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INFLUENCE OF VISION IN ACQUIRING SKILL

BY H. A. CARR AND ELLA B. OSBOURN

University of Chicago

In an article in a recent number of this JOURNAL, one of the writers[1] reported the results of an experiment on the value of vision in maze learning. A certain amount of vision was found to be extremely effective in reducing the number of trials and errors required to master the problem so that the maze could finally be traversed without the aid of vision. Under the conditions of this experiment, the subjects could see not only the movements of the arm, hand and stylus, but also the pattern of the maze. Vision, however, did not enable the subjects to distinguish the true pathway from the cul de sacs. The motion of the hand and stylus was thus perceived in relation to the fixed pattern of the maze, and presumably this condition materially aided the subjects in identifying and remembering the correct pathway in visual terms. The conditions were somewhat analogous to those involved in learning to write, for in this case the motions of the hand and pen are perceived in relation to the permanent record of those movements.

The experimental procedure, however, failed to duplicate the conditions which obtain during the acquisition of most types of skill, such as walking, dancing, swimming, ball tossing, and typewriting by the touch method, for obviously in these cases the movements are not perceived in relation to some objective system of coördinates.

It was the purpose of the present experiment to create a situation more similar to those under which most acts of

[1] Harvey Carr, 'Influence of Visual Guidance in Maze Learning,' JOUR. EXPER. PSYCHOL., IV.

skill are acquired. As a consequence our experimental procedure was arranged with a view to excluding the sight of the maze pattern while permitting the subjects to see the movements of the arm and stylus. An ordinary form of stylus maze was employed, differing in size and pattern from that previously used. The particular device used to exclude the sight of the maze pattern was a circular disc of thin aluminum plate, firmly attached to the stylus so as just to clear the surface of the maze when the stylus was in position. This disc was sufficiently large to cover completely the maze pattern for all possible positions of the stylus in the maze. Thus when vision was permitted, the subjects could see only the motion of the hand and the stylus with its attached disc, while any perception of this motion in relation to the objective pattern of the maze was prevented.

Five groups of subjects were tested. All subjects were without previous maze experience. All members of group I. learned the maze entirely without the aid of vision. This group is termed the 'standard.' Vision was excluded in the customary manner by the use of a cloth screen. To make the conditions comparable, the members of this group were also required to use the stylus with the attached disc. Groups II., III., and IV. were permitted the use of vision during the initial three, five and seven trials respectively and were then required to complete the mastery of the maze with vision excluded by means of the screen. The members of group V. were permitted the use of vision until each individual was able to run three perfect trials in succession, and then were required to complete the mastery of the problem with vision excluded. The average number of trials in which vision was permitted (not counting the three perfect runs) was 14.9.

The comparative data are given in Tables I. and II. In Table I. are given the visual conditions of learning, the number of individuals in each group, the average number of trials and errors required to learn, and the percentages of saving in trials and errors due to vision. In Table II. the error data are further analyzed into the two classes of

TABLE I

GROSS RECORDS AND PERCENTAGES OF SAVING DUE TO VISION

Groups	Number of Subjects	Trials	Errors	Percentages of Saving	
				Trials	Errors
I. Standard	15	22.1	181.4	—	—
II. 3 trials	15	16.7	87.4	24.4	51.8
III. 5 trials	15	18.9	95.4	14.4	47.4
IV. 7 trials	15	17.2	79.7	22.1	56.0
V. 14.9 trials	17	17.7	61.4	19.9	66.1

TABLE II

FORWARD AND BACKWARD ERRORS

Groups	Number of Subjects	For-ward Errors	Back-ward Errors	Percentages of Saving	
				For.	Back.
I. Standard	15	58.6	122.8	—	—
II. 3 trials	15	30.7	56.7	47.5	53.8
III. 5 trials	15	32.6	62.8	44.2	48.9
IV. 7 trials	15	33.6	46.1	42.6	62.4
V. 14.9 trials	17	28.5	32.9	51.3	73.2

forward and backward errors. The forward errors consist of all entrances into cul de sacs while the subject is moving forward in the direction of the goal. All sections of the true path retraced and all cul de sacs entered while the subject is moving back toward the entrance of the maze are counted as backward errors. These data justify the following conclusions:

1. Vision, when permitted, is always effective in reducing the number of trials and errors involved in acquiring the ability to run the maze without the aid of vision.

2. Vision is much more effective in reducing the number of errors than of trials.

3. As the amount of vision is increased, its influence upon errors at first decreases and then increases. This statement applies to both types of error.

4. No definite relationship apparently obtains between the amount of vision and its effect upon the number of trials necessary for learning.

5. Vision is more effective in the elimination of the backward errors than in the elimination of the forward ones.

Vision is effective in reducing the number of errors not only during the time when vision is permitted but also during the subsequent period of mastery in which the use of vision is excluded. These two stages in the learning process may be termed the visual and the post-visual periods respectively. Obviously the way in which vision operates will differ in the two cases, and hence any explanation of the effect of vision upon learning must consider these two periods separately.

The error data for the two periods of learning are given in Table III. The first column states the length of the visual

TABLE III

ERROR RECORDS FOR VISUAL AND POST-VISUAL PERIODS

Groups	Visual Period				Post-Visual Period			
	Length	Total	Ave.	Per Cent.	Length	Total	Ave.	Per Cent.
II.....	3	25.8	8.6	39.1	13.7	68.2	4.9	59.0
III.....	5	40.2	8.04	50.5	13.9	45.8	3.3	43.9
IV.....	7	39.6	5.65	42.2	10.2	62.1	6.1	72.2
V.....	14.9	87.5	5.9	60.0	2.6	32.5	12.5	92.6

period. The second column gives the total number of errors prevented by vision during this period. The third column states the average saving of errors per trial, while the fourth column states the total saving in terms of its percentage relation to the number of errors made by the standard group for the corresponding period of learning. The remaining four columns give the same values for the post-visual period. The data of this table justify the following conclusions:

1. Vision is invariably effective in reducing the error scores for both the visual and the post-visual periods of learning.

2. Measured in terms of the total number of errors pre-

vented and the percentage of saving, vision exerted its greatest effect during the post-visual period in three of the four cases. Measured in terms of the number of errors prevented per trial, vision was most effective during the visual period for its shorter lengths, but when the visual period is long the subsequent effect of vision is the greater.

3. With the exception of the records for group IV., the total and the percentage values for the visual period increase with the amount of vision permitted. With the same exception, the opposite relation obtains for the average values.

4. Measured in terms of the average and percentage values, the influence of vision during the post-visual period at first decreases and then increases with the amount of vision permitted. No very definite statement can be made concerning the relation between the total values and the amount of vision, unless the values for group IV. be regarded as an exception.

These values for the post-visual period are complicated by the fact that the length of this period is highly variable from group to group.

5. Vision was not very effective during the initial trial of the visual period. The initial error score of the standard group was 23.7, while the corresponding value for the 62 individuals who were permitted the use of vision was 20.

6. The removal of vision operated to increase the error scores to a slight extent during the first two trials of the post-visual period. The comparative data are not given in the tables.

7. The subsequent effect of a given amount of vision is almost as great as the effect that would have been obtained if the use of vision had been continued until the maze was learned. This statement is based upon the data of Table IV. In the middle columns are given the error records of groups II., III., and IV. for the post-visual period. The error records for the standard group for the corresponding periods of learning are given in the first column, and similar data for the group that was permitted the use of vision for the entire period of learning are given in the final column.

Presumably the records of groups II., III., and IV. would have approximated those of group V. if the use of vision had not been discarded. In other words, three trials with

TABLE IV

ERROR RECORDS FOR POST-VISUAL PERIOD

Group I.	Group II.	Group III.	Group IV.	Group V.
115.6	47.3			28.2
100.4		54.6		23.6
88.0			25.8	21.0

vision (group II.) operated to reduce the error record during the post-visual period of learning from 115.6 to 47.3, while the continuance of vision throughout this period would have further reduced this score by 19.1 errors. Likewise a continuance of vision would have reduced the error scores of groups III. and IV. by 31.0 and 4.8 respectively.

8. The mastery of the maze in visual terms does not necessarily enable the subject to traverse it successfully with vision excluded. Group V. that was permitted the use of vision until each individual was able to run three perfect trials in succession required on the average 2.6 more trials to learn to run it when vision was excluded. Individuals differ in their ability in this respect. Of the seventeen subjects, nine ran the maze perfectly when the possibility of vision was eliminated, while five required from 8 to 15 trials with an average of about one error per trial to relearn it under the new conditions.

There are several ways in which vision may manifest its effectiveness during the visual period. It may give the subject greater confidence and assurance and thus eliminate much of the futile and aimless exploration characteristic of the periods in which the subject becomes confused, lost or discouraged. It may permit of a more accurate and definite localization of the goal and enable the subject to attain a better conception of the course of the true pathway. It may also aid in the definition of the cul de sacs.

On the basis of the above conceptions, one might expect

that vision would be effective as long as its use is permitted, and hence that the total number of errors prevented would increase with the length of the visual period. With the exception of the records of group IV., this assumption is justified by the data of Table III. However, one cannot assume that the number of errors prevented will be proportional to the number of trials, for naturally more errors will be prevented in the initial trials in which many errors are normally made. Rather one should expect that the number of errors prevented per trial will decrease as the amount of vision is increased, and with one exception this assumption is also justified by the records.

The exceptional records of group IV. for the visual period may find their explanation in the following conception: During the course of the experiment, it was observed that the subjects invariably watched their movements very closely during the first few trials, then attempted to dispense with its use for several trials, and finally employed it again in the later trials. On the basis of this observation, it is suggested that the relatively poor records of group IV. may be due to the fact that they attempted to dispense with the use of vision from the fifth to the seventh trials, while the excellent records of group V. are due to the fact that vision was again employed after the period in which its use was discarded. Of course it is also possible that the records of group IV. may be due to some chance factor.

The effectiveness of vision during the post-visual period is due to one or both of two factors: (1) A memory of the visual data concerning the maze pattern acquired during the preceding period, and (2) to a more perfect tactual motor coördination resulting from the previous visual guidance. There are no data which indicate the relative effectiveness of these two factors. So far as the first factor is concerned, we would assume that the more adequate and accurate the conception, the greater will be its effectiveness, and that its accuracy, within limits, will vary directly with the length of the visual period. The effectiveness of the tactual motor coördination will vary with the degree of its perfection, and

this latter may be expected to vary with the number of trials in which vision is permitted. In other words, it may be assumed that the effectiveness of the two factors during the post-visual period will increase in a general way with the length of the preceding visual period, and hence that, all other variables being neglected, the total number of errors prevented during the post-visual period will increase with the number of trials in which the use of vision was permitted.

The influence of these factors is, however, to a considerable extent counterbalanced by several other variables: One is the length of the post-visual period. It is obvious that, other things being equal, the shorter the visual period, the longer will be the post-visual period, and the greater will be the number of errors prevented. A second is the position at which the post-visual period begins. With a short visual period, the after effects of vision will be exerted at a time when more errors are normally made than is the case with a longer visual period. Third, the factor of visual memory is likely to disintegrate with time. So far as the first two variables are concerned, it is evident that the total number of errors prevented during the post-visual period will vary inversely with the length of the previous visual period. As to the third variable, it is evident that its effectiveness will tend to decrease with the length of the post-visual period and hence to vary inversely with the length of the visual period.

The total amount of error saved during the post-visual period is thus related to the length of the preceding visual period in two opposing ways,—one in which the number of errors saved will vary with its length, and one in which the number will vary inversely with the length. These two antagonistic tendencies may well account for the fact (Table III.) that no definite relation obtains between the amount saved during the post-visual period and the number of trials in which vision was permitted. The lack of any correlation between the two sets of data may also be due, in part, to the peculiar records of group IV. for the visual period. If vision was not effectively utilized throughout the visual

period, this fact would obviously complicate its post-visual effect.

As a subsidiary experiment, we investigated the influence of the sudden introduction of vision upon the performance of a thoroughly mastered act, and the relation between the amount of such disturbance and the extent to which vision was employed in its acquisition.

Group I. had been required to master the maze without any visual aid. After the maze was learned in this manner, the screen was removed and the subjects were required to run the maze with vision permitted. Likewise all those groups that were permitted the use of vision during the initial trials and had acquired the ability to run the maze with vision excluded were now tested as to their ability to perform this act while visually observing it. In all cases the subjects were tested until all disturbance due to the introduction of vision was eliminated and three perfect successive trials were obtained.

The comparative data are given in Table V. In the

TABLE V

INFLUENCE OF VISION AFTER LEARNING

Groups	Number of Subjects	Per Cent. of Subjects Affected	Ave. Trials	Ave. Errors
I. Standard	15	87	6.9	7.7
II. 3 trials	15	27	2.0	2.2
III. 5 trials	15	53	3.2	3.7
IV. 7 trials	15	93	5.5	7.8
V. 14.9 trials	17	65	4.1	4.0

third column are given the percentages of the individuals affected for the various groups. The fourth column gives the average number of trials per affected individual required to eliminate the disturbance, while in the last column are found the average number of errors per affected individual involved in learning to adjust to the novel situation. Obviously these values are a measure of the degree of the resulting disturbance. These data justify the following conclusions:

1. The majority of the individuals (65 per cent.) were

disturbed by the introduction of vision, and this disturbance persisted for from one to fifteen trials. Usually not more than one or two errors were made per trial. The disruptive influence of vision was slight but quite difficult to eradicate.

2. A very considerable number of the subjects were immune to this influence and were able to traverse the maze without error.

3. With the exception of group IV., those subjects who had learned the act with visual aid were less disturbed by the introduction of vision than were those individuals (group I.) who had been denied that aid. The standard group (I.) and that permitted seven trials with vision (group IV.) were about equally affected.

4. With the exception of group IV., the amount of the resulting disturbance, measured in terms of the number affected and the number of trials and errors required to readjust to the situation, varies directly with the amount of visual guidance employed in acquiring the act.

The fact that the standard group that had been denied the use of vision in learning the maze was the most disturbed by the introduction of vision is to be explained largely in terms of the illusory conception of the magnitude of the movements which subjects normally develop under these circumstances. It is a well-known fact that subjects who learn a maze with vision excluded build up some sort of a conception of its visual appearance, and that almost invariably they grossly overestimate its dimensions. Naturally all subjects who are permitted the use of vision in learning the maze will develop a more correct conception of its magnitude. As a consequence the members of the standard group, when vision is introduced, will be distracted by the disparity between their conceptual and perceptual impressions, and will make a number of errors in so far as they attempt to guide their movements in terms of vision.

One would naturally expect that the greater the amount of vision involved in the acquisition of an act, the less will be the disturbance resulting from its later introduction. As a matter of fact the opposite relation obtains and the fact

is not readily explained. Two suggestions may be offered: (1) Overconfidence and carelessness. The more nearly the act was learned while vision was permitted, the greater is the subject's confidence in his ability to run the maze correctly when vision is again introduced, and this confidence begets carelessness and resulting error. Especially does this explanation apply to the members of group V. They were permitted the use of vision until they ran three perfect trials in succession, and were then requested to make three more perfect runs with vision excluded. By this time, they were overconfident, somewhat bored and quite careless, and errors were made as a consequence. (2) Inaccuracy of visual conception. While the visual groups developed a more accurate conception of the magnitude of the movements than did the standard group, yet their conception of the details of the maze pattern may be more inaccurate. The greater the amount of vision permitted, the more detailed will be the conceptual schema developed, and it is assumed that the greater the wealth of detail, the more numerous are the possibilities of error. Mistakes will naturally be made in so far as these subjects attempt to guide their movements by means of these erroneous notions.

The fact that such a large number of individuals in all groups were not disturbed by the introduction of vision indicates that individuals differ very materially in the extent to which they normally rely upon a visual control in acquiring and performing such an act of skill.

DIFFERENCES IN THE ORAL RESPONSES TO WORDS OF GENERAL AND OF LOCAL SIGNIFICANCE

BY VIVIENNE R. McCLATCHY

University of Texas

This investigation in free association is concerned with an experimental study of differences—both quantitative and qualitative—in the oral responses to words of general and words of local significance. Interesting and significant facts relating to temperament and to mental mechanisms in general have been found by various writers in the qualitative and quantitative data furnished by word association experiments. Jung (3) analyzed and classified the kinds of responses given by various types of individuals, but he also noted in a general way the presence of certain signs, such as long reaction time, that he believed to be indicators of emotional complexes. Hull and Lugoff (2) made a study of various complex signs in free associations, chief among which were repetition of stimulus words, extremely long and extremely short reaction time, and complete inability to make any response to certain stimulus words. Dooley (1) is interested in using these various signs as means of studying common complexes rather than individual complexes. She is dissatisfied as to the use and value of reaction time length in word association studies. In the following investigation, conducted with 90 university students of undergraduate rank, 42 of whom were boys and 48 girls, I have attempted to determine the associational tendencies as indicated (*a*) by the reaction time, and (*b*) by the type of oral responses given by normal individuals to oral stimuli, when stimulus words of different classifications were used. The classifications, so far as stimulus words are concerned, are of two kinds, *i.e.*, general and local. So far as responses are concerned, I have assumed, *a priori*, that I should find both personal and impersonal answers, as well

as responses of general and of local import. In other words, the responses to each of these groups could be classified in two ways—local or general, and personal or impersonal.

For stimulus words, two groups were used—words which had one of two connotative values. Either they were words of general significance, which might have been used with any group of normal people, or they were the names of local places which the students frequent, or the names of local organizations, or words to which the students themselves had assigned peculiar meanings. Forty-four of each kind, promiscuously sorted, were used. For convenience of the reader, I shall list these separately:

General Words	*Local Words*
long	McFadden's (drug store)
Dodge automobile	chili (favorite article of food)
coca cola	X———— (name of dean)
slow	Theta fraternity
ideal	Sigma Chi fraternity
cigaret	Woman's Building (dormitory)
over	Crescent Theatre
poker	Lake Austin
justice	Beta fraternity
sheep	Kappa fraternity
stem	Kappa Alpha fraternity
bank check	Students' Council
whistle	German (weekly dance)
automobile	Pi Phi fraternity
beautiful	problems (mathematics and physics)
fraternity pin	Cactus Tea Room
river	Newman Hall (girls' dormitory)
white	Deep Eddy (swimming resort)
rush	Curtain Club (dramatic club)
swift	"Pig" (campus dog)
wicked	Driskill Hotel
toddling	S. A. E. fraternity
fraternity house	buzzard (student who idles on campus)
heavy	San Marcos (pleasure resort)

hammer	Maverick Cafe
lion	Post Road (popular drive)
Ford automobile	Co-op (university book store)
prejudice	"Cosine" (nickname for mathematics professor)
cheese	date (social engagement)
fish	library
afraid	grave digger (gossip)
drink	Blunderbuss (April 1st journal)
comfort	Griffith's Drug Store
Buick automobile	Phi Mu fraternity
fruit	"B" Hall (boys' dormitory)
dance favors	campus
smooth	Majestic Theatre
mathematics	Clark Field (athletic field)
butterfly	Zeta fraternity
Bible	quiz
sweet	psychology
Stutz automobile	Kappa Sigma fraternity
false	Arrow-head (social club)
crap shooting	bust (colloquial for failure)

This list of words, as oral stimuli, was given individually to each of the ninety students. The oral responses and the reaction time, measured by a stop-watch graduated to one one-hundredth of a minute, were recorded on a blank arranged for the purpose.

The responses were sorted as to whether they were general and local, as defined above, or personal and impersonal. By personal responses, I mean those which have an obvious personal significance, such as 'sister—Mary,' 'cash—none'; while impersonal responses are those which seem to have no peculiar personal meaning and which might have been given by any normal person under any circumstances.

Table A contains the list of general stimulus words with the number of responses classified in two ways—local and general, or personal and impersonal. Columns II. and III. represent one classification of the ninety responses given to

each of the stimulus words, and Columns IV. and V. represent another classification of the same responses. For ex-

TABLE A

FREQUENCY TABLE FOR GENERAL STIMULUS WORDS

Stimulus			Number of Responses				
I	II	III	IV	V	VI	VII	VIII
	Local	General	Personal	Impersonal	Total Time	Av.T.	Av.D
Dodge automobile	34	56	43	47	.47	.054	.028
long	5	85	7	83	.27	.03	.011
coke	56	34	17	73	.40	.044	.014
rush	48	42	30	60	.35	.039	.012
swift	5	85	8	82	.36	.04	.014
wicked	1	89	4	86	.34	.037	.013
toddling	57	33	18	72	.33	.036	.007
fraternity house	75	15	15	75	.46	.051	.016
heavy	9	81	12	78	.39	.043	.021
hammer	2	88	2	88	.30	.033	.009
lion	3	87	4	86	.33	.036	.007
Ford automobile	11	79	36	54	.48	.053	.021
prejudice	14	76	24	66	.47	.052	.021
cheese	2	88	6	84	.28	.031	.006
fish	11	79	8	82	.36	.04	.014
afraid	0	90	7	83	.38	.042	.015
drink	5	85	7	83	.36	.04	.013
comfort	0	90	40	50	.37	.041	.025
Buick automobile	19	71	45	45	.47	.052	.020
fruit	1	89	16	74	.31	.034	.008
dance favors	26	64	42	48	.49	.054	.015
smooth	1	89	7	83	.31	.034	.005
mathematics	76	14	55	35	.40	.044	.017
butterfly	31	59	11	79	.37	.041	.011
Bible	16	74	10	80	.33	.037	.013
Stutz automobile	29	61	34	56	.39	.043	.010
sweet	0	90	6	84	.23	.025	.006
false	4	86	4	86	.39	.043	.016
crap shooting	3	87	12	78	.33	.036	.008
slow	2	88	3	87	.28	.031	.014
ideal	6	84	17	73	.77	.085	.007
cigaret	6	84	9	81	.34	.037	.015
over	2	88	1	89	.32	.035	.010
poker	3	87	10	80	.39	.043	.014
justice	2	88	4	86	.41	.045	.022
sheep	0	90	2	88	.35	.039	.017
stem	1	89	3	87	.34	.037	.010
bank check	20	70	37	53	.42	.046	.016
whistle	23	67	24	66	.40	.044	.018
automobile	2	88	6	84	.33	.036	.012
beautiful	8	82	14	76	.32	.035	.012
fraternity pin	37	53	36	54	.49	.054	.020
river	19	71	1	89	.29	.032	.008
white	0	90	1	89	.23	.025	.006

ample, where Dodge Automobile was the stimulus word, the numbers 34 and 56 represent the ninety responses given to the word; the numbers 43 and 47 represent the same responses in a different classification. Column VI. represents the total time for the responses to each stimulus word; Column VII. is the average time; and Column VIII. is the average deviation.

Table B contains the same sort of information in regard to local stimulus words.

For quantitative investigation we may tabulate thus:

To General Stimulus Words from a Total of	3,960
Responses of Local Significance	675
Responses of General Significance	3,285
or	
Responses of a Personal Nature	698
Responses of an Impersonal Nature	3,262
To Local Stimulus Words from a Total of	3,960
Responses of Local Significance	2,709
Responses of General Significance	1,251
or	
Responses of Personal Nature	1,051
Responses of Impersonal Nature	2,919

These results permit the following interpretations: (*A*) for stimulus words of a general nature, out of 3,960 responses, 17 per cent. were of local significance while the larger per cent. (83) were of general significance; (*B*) these same responses classified as personal and impersonal showed 17.6 per cent. personal and 82.4 per cent. impersonal; (*C*) where words of peculiar local significance were used as stimulus words, out of 3,960 responses 68 per cent. were local, as opposed to 32 per cent. general; (*D*) these same responses in the personal-impersonal classification were 26 per cent. personal and 74 per cent. impersonal.

Comparing the two groups, I find that general stimulus words get one fourth as many local responses and more than two and one half times as many general responses as do local stimulus words. When the responses are classified as personal and impersonal, the local stimulus words get about one and one half times as many responses of a personal nature and not quite an equal number of impersonal responses as do the general stimulus words.

The time is interesting in showing a difference between the two groups of stimulus words. The responses to the general

TABLE B

FREQUENCY TABLE FOR LOCAL STIMULUS WORDS

Stimulus	Number of Responses						
I	II	III	IV	V	VI	VII	VIII
	Local	General	Personal	Impersonal	Total Time	Av.T.	Av.D.
McFadden's	72	18	6	84	.35	.039	.011
chili	17	73	15	75	.28	.031	.008
Dean's name	88	2	27	63	.47	.052	.022
Curtain Club	18	72	23	67	.42	.046	.026
"Pig"	7	83	10	80	.35	.039	.014
Driskill Hotel	49	41	32	58	.48	.053	.024
S. A. E. Fraternity	78	12	48	42	.53	.058	.017
buzzard	14	76	2	88	.37	.041	.015
San Marcos	55	35	9	81	.37	.041	.012
Maverick Cafe	34	56	24	66	.42	.046	.011
Post Road	24	66	25	65	.47	.052	.017
Co-op	34	56	8	82	.38	.042	.016
cosine	12	78	12	78	.38	.042	.009
date	51	39	63	27	.48	.053	.029
library	32	58	15	75	.32	.035	.009
grave digger	8	82	14	76	.42	.046	.012
Blunderbuss	81	9	21	69	.40	.044	.015
Griffith's	59	31	7	83	.45	.050	.019
Phi Mu Fraternity	84	6	54	36	.65	.072	.025
B. Hall	90	0	10	80	.40	.044	.016
campus	53	37	10	80	.38	.042	.010
Majestic Theatre	54	36	21	69	.40	.044	.019
Clark Field	87	3	11	79	.32	.035	.008
Zeta Fraternity	70	20	49	41	.45	.050	.026
quiz	90	0	30	60	.52	.058	.034
psychology	73	17	51	39	.41	.045	.018
Kappa Sigma Fraternity	87	3	37	53	.55	.061	.035
Arrowhead Club	84	6	15	75	.41	.045	.011
bust	69	21	19	71	.39	.043	.012
Theta Fraternity	85	5	42	48	.55	.061	.026
Sigma Chi Fraternity	83	7	34	56	.48	.053	.028
Woman's Building	74	16	34	56	.41	.045	.019
Crescent Theatre	71	19	15	75	.41	.045	.012
Lake Austin	67	23	11	79	.35	.039	.011
Beta Fraternity	78	12	40	50	.55	.061	.024
Kappa Fraternity	80	10	47	43	.52	.058	.021
K. A. Fraternity	79	11	27	63	.54	.060	.016
Students' Council	81	9	30	60	.50	.055	.020
German	63	27	8	82	.33	.036	.011
Pi Phi Fraternity	79	11	29	61	.46	.051	.014
problems	84	6	12	78	.31	.035	.030
Cactus Tea Room	69	21	16	74	.41	.045	.012
Newman Hall	52	38	22	68	.43	.047	.016
Deep Eddy	90	0	6	84	.29	.032	.008

stimulus words ranged from .085 minute for *ideal* to .025 minute for *sweet* and *white*. The responses to the local stimulus words ranged from .072 for *Phi Mu Fraternity* to .031 for *chili*. The average for the general stimulus words was .041, while the average for the local stimulus words was .047, a slight increase. In general, we may say that the responses to the local stimulus words were somewhat slower than to the general stimulus words.

From the data in the tables as well as from a study of the actual responses, the following results are suggested:

1. As has been indicated elsewhere, the average time for responses to local stimuli was somewhat longer than that for responses to general stimulus words. If interpreted, as is usually done in the case of long reaction time records, this result would seem to indicate that on the whole there was more of a tendency to inhibitions for local stimulus words than for words of a general nature. The next problem was to find where these inhibitions existed if at all. Choosing those stimulus words which showed an average reaction time of .05 or above, I find that nine out of seventeen of these were the names of Greek letter fraternities. The individual responses were indicative of a very prevalent anti-fraternity spirit known to be present in university circles among those who are not members of fraternities. One individual who had been no little chagrined at not having been invited to join a fraternity, and who had heard much adverse criticism at home in regard to fraternities gave very long reaction times and, on being questioned, seemed utterly incapable of expressing herself sufficiently to make any explanations. Several other non-fraternity individuals showed rather quick reaction time except in the cases where the names of fraternities were the stimuli. In these cases the reaction times were long and the responses obviously 'cover reactions.' Another of those stimulus words showing long reaction time was the name of the dean before whom the students have to appear for infringement of rules either of conduct or of scholarship. The name of a local hotel, where many of the student social affairs are held, gave an average reaction time

of .052 minute; 'Post Road,' the name of the best automobile drive in this part of the country, suggested various escapades by its average time of .052; 'date,' used in the sense of social engagement, brought out many possibilities of sex inhibitions; 'Blunderbuss,' the name of an April First yellow journal which has caused the expulsion of several students from time to time, came in this group with an average time of .050; the word 'quiz' was peculiarly significant at the time the records were made, due perhaps to the fact that mid-term examinations were in progress; the one remaining stimulus word of this particular group of seventeen was 'students' council,' the name of the student government organization which investigates violations of the honor system, etc.

2. Scrutinizing the average deviations of the reaction time for each group, it was found that the average of the average deviations for the local stimulus words was higher than the average of the average deviations for the general stimulus words. This fact would seem to indicate that there was a greater tendency to individual variation in regard to time where stimulus words of local import were used than where general stimuli were employed.

3. With the result from item 2 in mind I then compiled the frequency tables, examples of which are found at the end of the article. From this compilation I found that the total number of different responses given to local stimulus words was 1,645, whereas the total number of responses given to general stimulus words was 1,531. This would seem to suggest that there was greater variety in the responses to local stimuli than to general stimuli, or less of a tendency to stereotypy.

4. In the case of general stimulus words the relation between the number of local responses and the number of general responses was very similar to the relation existing between the number of personal responses and the number of impersonal responses; this condition did not exist in the case of local stimuli where the responses were local by a large majority though singularly impersonal. General responses and im-

personal responses may both be assumed to carry a rather large degree of superficiality with them as opposed to local responses and personal responses which might seem to involve considerable feeling tone. If these last mentioned assumptions be granted, then I feel justified in saying that local stimulus words are accompanied by more feeling tone than are general stimulus words.

5. It is possible that association to general stimulus words come more readily because they are older, more frequently used, and therefore more firmly established than are associations to the local stimulus words. Such suggestion is not improbable when we recall that in certain cases of amnesia those usable associations which remain longest are those of early formation. The best evidence, however, which I have been able to gather does not support this possibility. In order to determine if such condition existed, I chose without regard to their time, four general stimulus words at random, *i.e.*, *long*, *swift*, *heavy*, and *fruit*. I then found that the four words showed an average reaction time of .0365 minute. I then chose in the same way four local stimulus words which I thought would probably not have any emotional tone connected with them. These were *chili*, *campus*, *library*, and *Co-op*, and their average reaction time was .0375. Then I chose four local stimulus words—*Post Road*, *Students' Council*, *Dean's Name*, and *S. A. E. Fraternity*—which I suspected of having an emotional tone. The average reaction time for these words was .0538. These comparisons show a greater difference of reaction time between the two groups of local stimulus words than between the general stimulus words and either of the groups of local words. This result leaves open the possibility of general stimulus associations coming more readily because they are older than associations to local words, but as far as this investigation is concerned, the possibility is unsupported.

6. Again it is possible that the slowness of reactions to local stimuli can be accounted for in the length of time involved in the mechanism of choice. As has been previously indicated, the variety of associations to local stimuli was

greater than that to general stimuli. It is possible that the increase in reaction time was due simply to the necessity of making a choice from a larger rather than a smaller number of associations.

I conclude, therefore, that so far as this particular investigation is concerned, we find (*a*) that the time required for response to general stimulus words or local stimulus words indicates more possibilities of inhibitions than does the response to general stimulus words; (*b*) there is a tendency to greater individual variation as far as time is concerned in responses to local stimuli than to general stimuli; (*c*) there is a greater variety of responses to local words than to general words; (*d*) there is more feeling tone attached to local stimuli than to general stimuli; or (*e*) associations to general stimuli are more firmly established and therefore appear more readily; (*f*) the mechanism of choice for a greater variety of associations increases the length of the reaction time.

EXAMPLE OF FREQUENCY TABLE

Stimulus—Deep Eddy

19	swim	2	suit
37	swimming	3	pool
1	river	1	picnic
3	bathing	2	beach
2	Sunday	1	Barton
1	dancing	1	last fall
4	water	1	good time
1	girl	1	boy
1	deep	1	date
1	lake	1	blue
1	bill board	1	spring board
5	boats	1	run
2	shute		

Stimulus—Newman Hall

10	girl	1	group
1	Spaniard	2	dance

19 girls	1 barbs
4 club	1 sign
1 news	1 B. Hall
1 building	1 mutton
3 brick	1 tough
21 Catholic	1 itch
6 name	1 Guadalupe
1 home	1 Edith
1 21st St.	1 Polly
2 nun	1 Cardinal
1 living room	1 sisters
1 grass	1 tall
1 cousin	1 rooms
1 position	

Stimulus—Problems

46 math (mathematics)	1 solid
1 slow	1 class
7 arithmetic	1 fish
2 box	1 physics
6 work	1 ethics
1 maze	1 books
5 trig (trigonometry)	1 tired
5 hard	1 plays
2 solve	1 pencil
1 example	1 tedious
1 algebra	1 sheets
2 analytics	

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THE CARDIO-PNEUMO-PSYCHOGRAM AND ITS USE IN THE STUDY OF THE EMOTIONS, WITH PRACTICAL APPLICATION

BY J. A. LARSON

Research Bureau, Berkeley School for Police

A Preliminary Communication

Over a year ago we started to use a deception test based upon the correlation between physiological and emotional activities.[1] In brief, the technique consists in securing a continuous blood-pressure curve taken synchronously with a respiratory and a timing curve. A chronograph, preferably of the Jacquet type, records the time in fifths of seconds, or greater intervals, while the reaction time is further obtained by the use of a signal magnet. Readings are taken on one arm by a Tycos sphygmomanometer (auscultatory method). A normal record is obtained without any stimulus word or action. This is followed by a short, prefatory, word preamble, while tracings are being recorded, after which a series of questions are given. The questions are very simple and direct and deal with indifferent matters as well as the subject under investigation. The questions are followed by having the subject or suspect reply to a set of Kent-Rosanoff stimulus words where the reaction time and the reply is recorded, tracings being obtained throughout. Every third word has to do with the subject of the investigation and the others act as controls. In cases where the subject is not a suspect, but thought to be suffering from a complex, the Woodworth questionnaire is used in place of questions concerning a crime. Marked variations at certain questions sometimes bring a complex to light. In addition to securing checks on a single suspect, it is often possible to obtain from forty to a hundred controls in some investigations. Thus, in certain cases a

[1] J. A. Larson, *Journal of the American Institute of Criminal Law and Criminology*, Feb., 1921.

crime is committed in a house in which there are many people. Here everyone is considered a suspect and is subjected to a test run, and it is finally ascertained that only one person is guilty, with the result that all of the other persons ran clear records. In every case the questions were the same and given so as not to arouse any emotion except that underlying the deception syndrome.

After subjecting several hundred individuals to the deception test the following results seem significant:

1. The association words with the time reaction do not give as satisfactory results as the cardio-respiratory changes. We can say this definitely in cases where the suspect has subsequently confessed where, although there were marked and striking changes in the tracings, the findings by the association method were not significant. Therefore, any test based upon the reaction time alone is not as satisfactory as the variations in the tracings.

2. Quantitative blood-pressure determinations, although highly satisfactory in Marston's work [1] are not infallible. Thus in many instances, suspects who subsequently confessed did not show a rise of blood pressure great enough to be classified as a rise due to deception according to Marston. In many cases the cardio-respiratory curves show marked changes but no marked rise. This is to be expected, since the reaction of the suspect is going to vary according to his makeup. In some instances there is a sudden depression or a marked irregularity in rhythm. In others again there may be a marked increase in pressure which may be sudden and only last a few seconds. In some cases there is a sudden depression which is followed by a sort of compensatory increase.

The ordinary galvanometric methods are unsatisfactory for the same reason that quantitative blood-pressure determinations alone are. Instead of measuring the effects of the emotions in terms of blood pressure, they are studied in terms of changes in electrical resistance. These are un-

[1] Subsequently corroborated by H. E. Burtt, JOURNAL OF EXPERIMENTAL PSYCHOLOGY, Vol. IV., Nos. 1 and 2.

satisfactory as long as they are purely quantitative. Even when studied by means of the string galvanometer, the changes are not as easy to interpret as those in the pneumo-cardiograph.

3. In every case of deception, as checked by the cardio-pneumographic tracings and confession, there are marked changes in the records. The effect of the suppression or repression varies according to the temperament and physical character of the subject. There may be an increase or decrease in frequency, a marked depression or excitation or a more or less summative effect. H. E. Burtt has had definite results from the study of the respiratory curve alone.[1] He has studied the inspiration-expiration ratio by a special device and concluded that systolic blood pressure has a greater diagnostic value than the breathing. He obtained satisfactory results with the blood pressure even though the determinations were quantitative. As to the respiratory effects, he confirmed the findings of Benussi.[2] Burtt did his work with Marston. In addition to changes to the respiratory as noted by Burtt, other striking changes may be noted. There may be sudden inhibitions, summative and excitive effects.

4. In all cases of deception yet encountered the curve differs from that of the controls or the person who does not repress when questioned. In one or two cases where there were more than forty individuals involved, a preliminary test was held and from this two or perhaps three persons were picked for further investigation because of certain irregularities in their records. It subsequently developed that the effect was due to some other guilty association brought out by some stimulus word. After this association complex had been cleared up, the suspect was not affected by the question pertinent to the matter under investigation. In most cases there is a certain increase in tension in the controls, but this is of a general and not specific nature and is never marked and is easy to control. It appears, if at

[1] *Loc. cit.*

[2] 'Die Atmungsymptome der Luge,' *Archiv f. die Gesamte Psychologie*, 31: 1914, 244–273.

all, before the subject matter being investigated is touched upon. In framing and giving the stimulus words and questions proper precautions must be observed so that anger is not brought into play. It was found from the introspection of all of the subjects that there was never any anger aroused by any of the questions. The innocent, although they did not like the idea of being under suspicion, were always glad to be given an opportunity to vindicate themselves. In most cases they were much interested in the procedure. It might be mentioned here that the criminal record of the suspect in no way vitiates the emotional effect. In fact, it has been our experience that the recidivists are as much, if not more, affected as the first offender. In all of our cases of deception as checked by confession, there are very definite changes which are usually very pronounced. If a mistake is made in picking the culprit, it is due to misinterpretation.

5. The marked irregularities due to the effects of repression involved in the deception process disappear with the confession. If, however, a subject maintains a repression in successive tests, as a rule the effects continue, although he may know the stimulus word or question and when it is coming. In all cases up to the present time, whenever a subject is given the same test after confession, the record was clear. This same thing occurs when the suspect confesses when first questioned. The only difference, if any, in this curve is that the curve may show a slight effect before the confession is made.

6. Physiological or pathological factors do not appear to interfere with the test, provided that the subject is able to understand the questions and is not unfit mentally, as in some of the imbeciles and psychotic individuals. Thus if a subject has an irregular heart action, this is ascertained in his control and these effects are considered in the interpretation of the remainder of the record. If a subject is temporarily unstable because of some worry or physiological strain such as fatigue, menstruation, etc., this in no way interferes with the effect of emotional disturbances.

7. The cardio-respiratory curve is very useful in the study

of the emotions. Thus Sidis utilized the tracing obtained by the pneumograph to differentiate between the various elements in the case of a woman with a dual personality. Pictorially, the individual is represented in two ways, first by his present physical condition as shown in his heart and respiratory rhythm, and second by his reaction under stress, during questioning which may involve him in some crime. Thus a phlegmatic individual or a person with a hypo-thyroid insufficiency does not have the same type of curve or react in the same manner as the nervous, dynamic type or the individual with a condition of hyper-thyroidism. In the cardio-pneumo-psychograms the persons resolve themselves into groups which at first glance would seem to depend upon the temperaments or dispositions of the individuals. The cause, however, seems to be deeper, for the emotional reactions of an individual may depend entirely upon his physiological or pathological picture, as Dr. Berman emphasizes in his interesting work. Records may be grouped physiologically according to age, sex and other factors. In short any factor, normal or abnormal, which affects the heart and respiratory activity to any extent will show upon the record. This effect may be only transitory or of momentary duration. In some cases, as in certain girls during menstruation, there may be some changes from their records at other times. The pathological factors such as arterio-sclerosis, improper cardiac functioning due to disease, abnormal conditions induced by puberty, the menopause, pregnancy, etc., may give the records a typical appearance. In addition to depending upon physiological and pathological factors, the appearance of the record may vary with the mental condition of the subject, which in turn, however, depends upon underlying conditions. Thus a patient of the manic-depressive type may run a rather high or a sub-normal blood pressure, depending upon his condition. (See the work of Dr. J. D. Ball.) Persons who might be grouped together physiologically may be separated by their emotional reactions to various stimuli.

Interesting records have been obtained with drug addicts. The transition from the very sick, moaning, miserable indi-

vidual to the cheerful person may be shown graphically by comparing the record of the same man before and after an injection of morphine or other drug. This transition may occur within a few seconds.

With the aim in view of ascertaining how far abnormal individuals may be grouped according to type, we are making a survey of several thousand individuals in the penal and insane institutions of the state. These cases are treated first by securing controls and then probing for complexes. In this work we will have the assistance of Dr. J. D. Ball, as well as that of other psychiatrists.

The writer wishes to acknowledge his appreciation of the helpful coöperation and suggestions of Mr. Vollmer, of this department, throughout the entire investigation.

A STUDY IN GRADES AND GRADING UNDER A MILITARY SYSTEM

BY ROBERT L. BATES

Lieut. Col., and Associate Professor, Virginia Military Institute, Lexington, Va.

The data included in this study are those of the junior class of the academic school at the Virginia Military Institute. This report was, of necessity, limited to the one class. The group selected represents a good sample of the work that characterizes the institution. In common with most ranking military schools, a rigid system of grading obtains here. In this school is found, from one point of view, a peculiarly homogeneous group. However, as is true of any considerable number of individuals, there is a range of intellectual ability. The discipline is of the most democratic character, in that the same regimen holds alike for all. The time of the student is, in truth, wholly occupied with necessary military and scholastic duties. An honor system prevails in such manner that no suspicion attaches to a student's work. The system is inflexible to the point that each individual student knows his exact limitations as well as his rights. 'Shaving the regulations' is considered as reprehensible as an overt act. These facts might be deemed irrelevant did they not imply equal scholastic chance for all. Under this educational system definite abilities, especially in leadership, have a possibility to assert themselves and mediocrity is not concealed.

A daily rating for each student is required of the teacher, based on a quiz or the development of a topic on the blackboard. In the matter of rating students, each teacher grades independently with but incidental knowledge of the marks given in departments other than his own. At the end of each bi-weekly interval the teacher submits a written report of all the daily grades for the period. These are so posted that each student not only has knowledge of his own marks but is aware of his relative standing with respect to other

members of his own or of different departments. At the end of each four-week period a monthly report is compiled in like manner, though not for publication. These latter supply the office data, and are the basis of individual reports that are sent to the student's parent or guardian. At the end of each semester examinations are conducted and these are rigorously graded. A period of three weeks is given to examinations at the end of each semester. In that time three examination periods are allotted to each subject pursued. The subject is, prior to examinations, divided into three parts and each test is based upon the respective part in consecutive order. This necessitates the student's review of but a limited portion of the semester's work for each part of the examination. 'Cramming' can be resorted to under the system, but the method of rating employed discourages it and minimizes its results. An examination period is of three hours' duration.

Promotion, success or failure in a course, is determined by effecting a resultant of class and examination marks, class marks being weighted as according to the formula,

$$\frac{2\ \textit{Class mark} + 1\ \textit{Examination mark}}{3}$$

The final class mark is the average of all recitations in the particular subject for the semester. For a passing mark no final grade must fall below 7.0 whether it be examination or class grade. This procedure, as previously noted, helps to offset the effects of 'cramming' in the attempt to elevate a deficient final class mark and also to prevent the cessation of work where the student already has a high mark. The standard in every instance is 10.0 regarded as perfect, 7.5 as proficient and 0 as complete failure. To receive credit for a course of study a grade of 7.5 must be obtained as a resultant of the above formula. Classes range in size from 16 to 25 individuals. The group reported here consisted of 34 individuals in two sections, each of which recited the same lessons but on alternate days. As duties are not relaxed on Saturdays, three recitations a week in each study is the rule.

The recitations are for one-hour periods barring, of course, the few minutes necessary to shift classes.

To the casual observer the system of rating students seems cumbersome, but after acquaintance with it and its exactions it becomes a matter of routine and is burdensome to neither student nor to teacher. Each student may know at any time how he is classified with respect to his fellow classmen.

As much has been written regarding the validity of marking systems, the chief question that arises is: Where an exacting system of rating students prevails, how do the ratings of the respective teachers compare? Growing out of this another question that arises is: To what extent do the findings corroborate or refute the experience of teachers in other institutions of learning? That these questions might be answered more fully measurements were made by the Thurstone Psychological Test (IV.).

The final grades for five studies that closely resembled each other in the technique of presentation were examined. No two studies were conducted by the same teacher. It may be a significant fact that the teachers of American Literature and of History are graduates of this institution where, as students, they were familiar with the system. The instructor's task is to get the relative standing of the students as judged by their class work. It is almost impossible to obtain a numerical expression of quantitative ability. The merits or defects of a system of strict grading are best illustrated in the analysis of the data.

In making comparisons the Product-Moment method of Pearson was used to determine the coefficients of correlation. The methods employed to obtain averages and deviations were those of common practice.

The highest general average for any subject was for Psychology. The lowest average was in Political Science. The difference between these two extremes was .243. The highest and lowest medians were respectively for Psychology and History, these ranging from 8.23 to 7.90, with a difference of .330. The median and average for each subject taught

were nearly identical, the average in every instance being in excess of the median to a very small extent. This narrow variation for a series of averages indicates that grading was

DATA SHEET REPRESENTING GRADES GIVEN IN THE VARIOUS SUBJECTS AND THEIR AVERAGES

Individ.	Avs. of Grades	Psychology	Political Sci.	American Lit.	English Lit.	History	Thurstone Test
1.....	9.22	9.19	9.44	9.16	9.12	9.21	107
2.....	9.15	9.06	9.33	9.06	9.11	9.18	116
3.....	9.12	8.74	9.13	9.24	9.39	9.09	132
4.....	9.06	9.33	9.20	8.67	9.00	9.11	63
5.....	8.78	9.05	8.83	8.73	8.79	8.50	111
6.....	8.68	8.82	8.83	8.61	8.71	8.42	120
7.....	8.65	8.55	8.74	8.52	8.68	8.78	106
8.....	8.48	8.22	8.95	8.48	8.46	8.28	86
9.....	8.33	8.19	8.16	8.62	8.35	8.32	80
10.....	8.29	8.56	8.03	8.38	8.14	8.32	76
11.....	8.22	8.60	8.12	8.13	8.31	7.94	98
12.....	8.18	8.15	7.93	8.26	8.36	8.21	89
13.....	8.17	9.00	8.06	8.08	8.09	7.63	87
14.....	8.14	8.00	7.90	8.23	8.36	8.23	80
15.....	8.06	8.24	7.66	8.18	8.20	8.00	87
16.....	8.06	8.02	8.15	8.07	7.93	8.11	61
17.....	8.04	8.20	7.94	7.91	7.94	8.23	91
18.....	8.04	8.24	7.99	7.97	8.23	7.76	112
19.....	8.02	8.25	7.81	8.05	8.19	7.78	99
20.....	8.01	8.09	7.76	8.14	8.31	7.74	98
21.....	8.00	8.00	7.91	8.34	7.97	7.78	130
22.....	8.00	7.88	7.81	7.99	7.96	8.36	94
23.....	7.97	8.35	7.91	8.08	7.76	7.75	104
24.....	7.95	8.05	7.78	8.14	7.91	7.86	94
25.....	7.87	8.09	7.83	7.92	7.89	7.61	79
26.....	7.87	8.24	7.77	8.00	7.63	7.72	89
27.....	7.82	8.25	7.83	7.82	7.43	7.77	69
28.....	7.74	7.65	7.85	7.81	7.79	7.62	62
29.....	7.68	7.59	7.72	7.87	7.48	7.72	78
30.....	7.68	7.81	7.89	7.48	7.54	7.66	59
31.....	7.63	7.64	7.58	7.72	7.66	7.56	72
32.....	7.56	7.52	7.62	7.63	7.50	7.55	89
33.....	7.49	7.82	7.44	7.59	7.16	7.46	58
34.....	7.45	7.66	7.22	7.53	7.42	7.43	97

AVERAGES AND DEVIATIONS

	Gen. Ave.	Psychol.	Pol. Sci.	Amer. Lit.	Eng. Lit.	Hist.	Thurstone
Average.....	8.159	8.276	8.033	8.188	8.140	8.079	90.40
Median.....	8.040	8.230	7.910	8.080	8.055	7.900	89.00
Av. Dev.....	.368	.375	.414	.344	.434	.421	15.45
S. D.....	.478	.474	.592	.437	.535	.507	19.25
Interquartile range.....	8.31	8.58	8.45	8.50	8.41	8.34	105.00
	7.84	8.00	7.79	7.91	7.78	7.72	78.00

COMPARISONS ON THE BASIS OF GENERAL AVERAGE OF GRADES

General Average	Average Grade in Quartile	Thurston Scores for Quartiles	Inter-quartile Score Average
9.22 8.31	8.859	103.64	
8.31 8.04	8.156	83.41	91.97
8.04 7.84	7.976	100.53	
7.84 7.45	7.645	73.94	

done on approximately the same scale by all five teachers. This fact is corroborated by a study of the interquartile range. The deviations, both average and standard, merely indicate the degree of dispersion of grades as posted by each teacher. Here we find no wide discrepancies because of individual variation in grading. The greater these deviations the greater is tendency of instructor to reward the better student with high grades while the grades of those doing less efficient work are reduced. The higher deviation from the mean also implies a greater tendency, on the part of the teacher, to approximate the quantitative scale. The lesser deviation from the mean proves a tendency to give neither extremely high grades nor to give extremely low ones. The dispersion as shown in the grades for the different subjects has a narrow range as compared with the Thurstone Psychological Test. But one inference can be made and that is,—there is a reluctance on the part of the teacher to mark the student of low grades as to his quantitative ability. In giving daily recitation marks the tendency is manifest, from a study of class marks, to give a grade of 10.0 only in exceptional instances. A recitation is deemed of high order when a mark between 9.0 and 9.5 is given. This is proved by the magnitude of the grade in the upper elevation of the first quartile. For the average individual reciting an average lesson a grade ranging from 8.0 to 8.5 is given. This is disclosed in the study both of the averages and of the inter-quartile range for the respective studies. It is also disclosed, on the basis of the general average, that 65 per cent. of the class make a grade of 8.0

or in excess. This is the median grade. It is also noted that the median is a close variant of the average. A high degree of uniformity is manifest for all subjects presented. A low class mark ranges from 7.0 to 7.5. This becomes evident upon a study of the lowermost quartile. Individual No. 34 has the lowest average, 7.45. The lowest single grade given in one subject was for Individual No. 33 who received a final grade of 7.16 in English Literature. It is common practice for a teacher to give less than a grade of 7.0 for a daily recitation, but compensatory grades in excess of this number maintain an average, for the less efficient student, at approximately the 7.5 position. A study of grade averages, however, manifests a reluctance on the part of the teacher to give less than 7.0 for a daily recitation. All grading ultimately reduces itself to the subjective process of judging, but the question of criterion for judgment is answered. The average recitation is estimated in terms of group performance.

The question may be raised that the grades as averaged include examination marks. It may be repeated that examination marks constitute the equivalent of but one third of the final grade. A collateral study of these discloses the fact that both examination and class grades constitute a close variant of each other.

SUBJECTS TAUGHT, COEFFICIENTS OF CORRELATION AND PROBABLE ERROR

Subjects Correlated			Coef. of Correlation	Probable Error
History	–	Amer. Lit.	.890	.024
History	–	English Lit.	.880	.026
History	–	Political Sci.	.868	.029
History	–	Psychology	.734	.053
English Lit.	–	American Lit.	.914	.019
English Lit.	–	Political Sci.	.839	.034
English Lit.	–	Psychology	.781	.045
Psychology	–	Political Sci.	.715	.057
Psychology	–	American Lit.	.802	.041
American Lit.	–	Political Sci.	.848	.033
Thurstone Test		American Lit.	.560	.079
		English Lit.	.547	.081
		History	.367	.100
		Political Sci.	.372	.099
		Psychology	.396	.098
		General Average	.467	.090

The coefficients of correlation existing between the various

subjects are high, ranging from .71 to .91, inclusive. This indicates that ability in class work is located by the different teachers and that the students are arranged in the order of their class proficiency. The coefficients exceed the probable error by numbers ranging from 12 to 45. Six times this relationship implies adequate correlation.

A study of the Thurstone Psychological rating in the light of individual averages for the various subjects taught discloses a wider dispersion than do class marks. When the coefficients of correlation between respective subjects and Thurstone Test, and between the various subjects themselves are compared, approximately the same correlative dispersion is found though, on the whole, the coefficients of the former are but half the latter. A range of .20 was found existing between the highest and lowest of each series of coefficients. The Thurstone coefficients range from 3.7 to 7 times the probable error. The data show that concomitant higher abilities lie in the first quartile for both test and study series. The inverse relationship prevails for the lowermost quartiles of test and final grade series. This is indicated under the 'comparison on basis of the general average.' The data also show that the English studies have a higher correlation with intellectual ability, as estimated in terms of the Thurstone Test, than have the other subjects. The highest coefficient of correlation is for the two Literature courses. On the basis of class proficiency, as measured by final grades, the first 25 percentile of grades had a Thurstone score average of 103.64, and the fourth 25 percentile had a similar average of 73.94. At first glance the inter-quartiles present an anomolous distribution. The third and second appear to be interchanged. This was an important factor in lowering the coefficients between the averages and the Psychological test. This distribution accentuates the reason why intelligence tests practically never correlate to a high degree with class marks. The reason is: the inter-quartiles contain the great mass of average ability. Concentration, application, diligence and interest distort the significance of test scores. In other words, these factors determine whether or not one is

to over-rank or under-rank (where the reverse factors hold) his intelligence rating. Where one has strong compensatory qualities—as exemplified for Individual No. 4—and in addition further complicates his endeavor by sacrificing speed for precision, a low score may obtain in spite of definite ability. Individual No. 34 admits a handicap of expression both oral and written. In the light of our limited data it would seem that both the upper elevation and the lower limit of scholastic attainment can be guaged by the intelligence rating, but it proves no criterion for the average, ordinary, normal ability.

Summary

I. Under a definite and strict system of grading, students can be rated successfully in the order of intellectual rank—qualitatively rather than quantitatively. What constitutes deficiency is a matter of judgment on the part of the teacher. In this group whose data are presented there is accord among instructors as to those who are deemed deficient. Psychological tests disclose a wider dispersion than do grades. The most deficient individual has a final grade not far below the passin · mark. This is the evidence of a qualitative rating.

II. A criterion for giving daily marks may be effected that gives the qualitative relationship between students where they are under constant observation in class. Where teachers are brought into the open with their daily grades, the ranking of intellectual ability becomes a matter of high correlative significance.

III. There is a close conformity between teachers' ratings and test scores for the first and fourth quartiles. The average grades are taken as the basis of comparison. An examination by Thurstone's Psychological Test is not wholly comparable to a system of marking, in that, the one necessarily assumes the existence of quantitative relationships and the other but approximates such relationships. In effect, the class grade is qualitative in its significance. This fact does not impair correlation of two such series.

Intelligence rating with approved tests becomes a positive, though not absolute, means of determining the intellectual

ability of the uppermost and the lowermost 25 percentiles of class proficiency. The intermediate quartiles are indicative of average ability. An individual of the average ability—in terms of the inter-quartile range on the Thurstone scale—may easily, even unintentionally, distort his class rating in a positive direction through concentration, application and interest. The 'personal equation,' in military parlance, plays a conspicuous part in securing high or low grades for the person of average ability.

STUDIES IN DISSOCIATION

I. Changes in the Auditory Threshold Induced by 'Crystal Gazing' [1]

BY LEE E. TRAVIS

The State University of Iowa

Introductory

1. *Statement of the Problem*

Recently there has been awakened a keen interest in the subconscious, abstraction, dissociation and related topics. These terms have often been used in a loose manner for the simple reason that so little is known about the phenomena which they purport to represent. We know very clearly what we mean by dissociation when the spinal cord is severed. Here the higher centers are actually separated from the lower spinal centers and the cortico-spinal neurones can no longer influence the motor responses determined by the impulse from the anterior horn cells. Since the reflexes are exaggerated under such conditions we can assume that the cerebral motor centers prevent the free play of simple reflexes.

The question arises as to whether voluntary abstraction or dissociation is at all related to actual operative dissociation. Can an individual voluntarily remove in any degree the inhibitory effect of cortical control and become a reflex machine? If all individuals cannot make this dissociation, are there some abnormal individuals who can do so? It is believed that these are fair questions to ask and the group of experiments that have been started, the first one of which is here reported, are being undertaken in an attempt to answer them.

This first report is a study of the changes in the auditory threshold for a relatively pure tone while 'crystal gazing.'

[1] This paper reports an experimental study carried on in the laboratory of the Psychological Clinic at the State University of Iowa under the direction of Professor John J. B. Morgan, Director of the Clinic.

2. *Previous Work*

There is very little to be found in the literature regarding the threshold of hearing during states of abstraction and mild dissociation. Dunlap[1] made some experiments on 'the effect of physical interruptions in subliminal phases,' which, although conducted from an altogether different point of view, hinted at the possibility of the threshold changing under certain conditions. His findings were the results of the summation effect. He used a subliminal sound of constant pitch, and the observers were to respond at the instant of the appearance and disappearance of the sound by predetermined clicks. In his experiments no attempts were made to alter the state of the observer after the normal threshold had been obtained.

Various writers have undoubtedly supposed that changes in the thresholds of the different senses occur under certain conditions and especially in states of hypnotism and somnambulism. Most of the evidence for such suppositions has been gathered from pathological cases, and suggests the need of carefully controlled experiments on normal subjects.

3. *Method and Apparatus*

The individuals who acted as observers for this investigation were either juniors, seniors or graduate students in the State University of Iowa.

The main piece of apparatus used in the investigation was the fourth model of the Iowa Pitch-Range Audiometer,[2] about which only a few facts will be presented in order to make the experiments clear. The tone generated is comparatively pure and can be varied in pitch from 30 v. d. to over 7,000 v. d. A tachometer is so calibrated that the pitch being generated can be read at any instant. The vibration frequency can be changed according to the desire of the experimenter by means of a rheostat which is connected in

[1] Studies from the California Psychological Laboratory, *Psychol. Rev.*, 1904, XI., 308.

[2] For a detailed description of this apparatus see paper by C. E. Seashore, *Lancet*, Oct. 15, 1919.

series with the motor. This adjustment was not used in this experiment since the pitch was kept constant throughout each experiment. The tone can be produced in the observer's receiver by connecting through a double-pole knife switch.

The resistance and hence the intensity of the tone as heard in the receiver is controlled by a device which consists of a series of twenty-one non-inductive resistances, installed in series with the generator. The first contact represents minimal intensity; according to experimental findings, it is not absolute zero resistance. The second contact has a resistance of .000025 ohm, and the other steps increase throughout the series by increments of 250%, totalling 2,264.3 ohms resistance for the maximal intensity. The loudness of the tone can be varied and designated in terms of these resistances, as each of these contacts becomes a connection with the watch case receiver terminals when the switch is shifted from one to the other.

The remainder of the apparatus consists of a clear crystal for gazing about 10 cm. in diameter, mounted over a 40-watt blue, mazda light bulb; a silent signal key; and a watch case receiver fastened to a head-clamp. The apparatus just described is in the light-proof, sound-proof, and jar-proof room of the psychological laboratory, while the audiometer is in an adjacent room.

The observer was seated comfortably at a table of average writing height with the watch-case receiver held firmly against one ear by the head-clamp. On the table was the silent signal key and the crystal, both of which could be moved to convenient places by the observer. The mercury key was quite sensitive, but still some effort was necessary to make contact. When contact was made, a buzzer sounded at the elbow of the experimenter. Each subject was instructed to try several positions with regard to key and crystal positions in order to find the easiest and most comfortable one.

The threshold of the observer was obtained under conditions identical with those under which the experiment was conducted except that there was no crystal gazing. The subject was to attend to the tones coming in the receiver

and respond every time he heard one. It might be well to state here that the threshold was ascertained both before and after the experiment.

The threshold having been found, the light was then switched on beneath the crystal into which the observer was asked to gaze. The crystal gave the appearance of the heavens on a clear, star-lit night. Each individual was told to begin the abstraction by recalling some pleasant experience or imagine himself in a wished-for or cherished situation. If these failed to cause him to forget his present surroundings, he was advised to attempt placing himself into a hypnagogic state. Several of the observers did approach this latter condition. When the subject fully understood what was expected of him, he was again left alone, to gaze into the crystal.

After from three to five minutes signals were given to the observer in series of three, the series at least a half minute apart. The intensity of the beginning tones was generally two contacts below the threshold. If the subject responded to tones of this intensity, the loudness was further decreased by one contact at a time until no responses were received. In case no responses were given on two contacts below normal threshold, the intensity was increased until the observer did respond.

The experiments lasted from one half hour to an hour, depending partly upon results obtained and partly upon the time which could be spent by the individuals acting as observers.

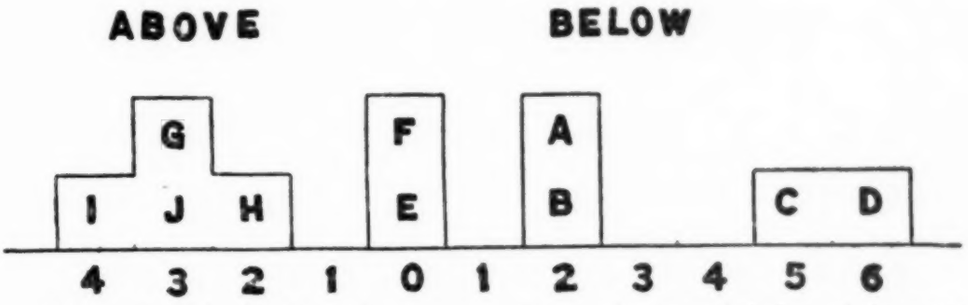
In the table each observer is represented by a capital letter. The thresholds, the tones of certain intensities and the responses to tones of certain intensities are represented by figures; each figure indicating the contact, a larger number being a louder tone. Column five is derived from columns three and four. To make this latter fact clear, let us take observer *D*. His normal threshold before and after the experiment was 14. Tones of intensity 8 were responded to accurately but no responses were made to tone of intensity 7. Hence his threshold during the experiment in a state of

4. *Experimental Data.*

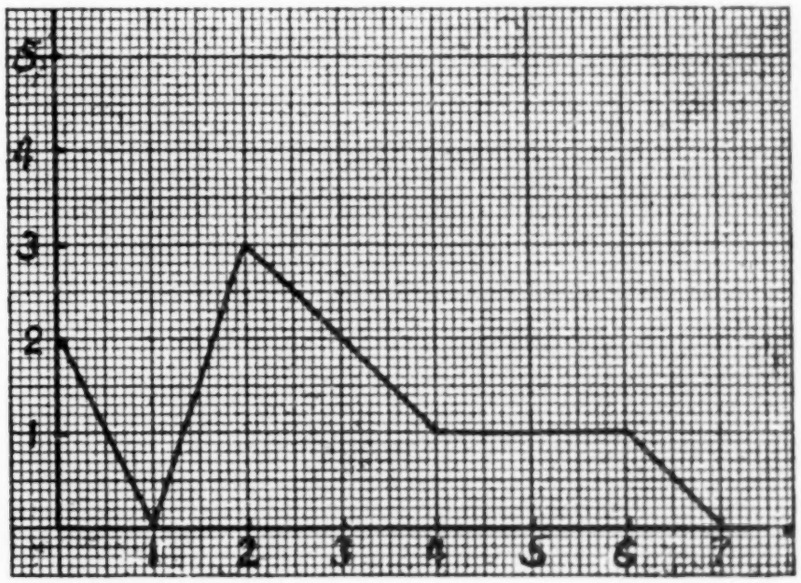
TABLE

Observers	Normal Threshold		Number of Tones of Certain Intensities													Number of Responses to Tones of Certain Intensities											Threshold During Experiment	Pitch	Length of Exp.	Time of Day	Errors
	Before	After	4	5	6	7	8	9	10	11	12	13	14	15	16	4	5	6	7	8	9	10	11	12	13	14	15	16					
A...	12	12					6	6	15											0	0	12							10	400 v. d.	60′	5–6 P.M.	3
B...	13	13								9	12	9											5	12	9				11	450 v. d.	40′	3:20–4 P.M.	6
C...	11	10	3	9	9	3	8	6								0	9	9	3	8	6								5	450 v. d.	60′	7–8 P.M.	6
D...	14	14				3	6	9	3	9	12								0	5	6	3	6	4					8	400 v. d.	30′	1:30–2 P.M.	2
E...	14	13									24	15	18											0	6	11			14–13	400 v. d.	40′	10:20–11 P.M.	1
F...	13	13								48	15	9											0	0	9				13	400 v. d.	30′	3:30–4 P.M.	0
G...	12	12							18	12	9	9	9	6								0	0	0	0	1	6		15	500 v. d.	60′	7:30–8:30 P.M.	0
H...	13	13								42	15	12	3	9									0	0	3	0	9		15	400 v. d.	45′	7–7:45 P.M.	0
I....	12	12							42	3	6	3	3	3	3							0	0	3	0	0	0	1	16	400 v. d.	30′	1–1:30 P.M.	0
J...	13	13								33	3	6	3	6	6								0	0	1	0	0	6	16	400 v./d.	40′	2–2:40 P.M.	2

abstraction was 8. In the cases of observers who required a tone above the normal threshold to provoke a response that tone to which they would react was taken as their threshold during the experiment.



GRAPH I. Distribution of various subjects above and below their normal threshold.



GRAPH II. Distribution of changes in threshold during abstraction regardless of the direction of the change.

Upon investigation of the table, we find that the normal thresholds of eight out of the ten observers were changed during the experiment. The two whose thresholds were not changed probably were unable to abstract or go into a hypnagogic state. Referring to Graph I., we note that the normal thresholds of four of the observers were lowered, four were raised and two remained unaltered. In other words, four of the observers responded to subliminal stimulation, four re-

quired a stimulus above the threshold before they would respond and two of the observers reacted to stimuli on the normal threshold. Concerning the two observers whose thresholds remained the same throughout the experiments, nothing can be said except that they undoubtedly did not enter into the state experienced by the others.

One observer's normal threshold was lowered six contacts, each contact being an increase in ohms resistance of 250 per cent. over the previous one. Another's threshold was raised four contacts during the experiment. The other observers fell between these two extremes. Observer *D* remembered making only two responses when as a matter of fact he made twenty-four. During the experiment he made two false responses.

The case of observer *C* was slightly different. He did not know whether he responded or not, but knew the tones 'were coming across.' *A* and *B* were aroused by the muscular activity involved in pressing the key, when they made responses. *A* stated that he 'caught himself pushing the key.'

Responding seemed to bring these two observers, *A* and *B*, back to a normal state and they would not react again to subliminal stimulation until from three to five minutes had elapsed.

All of the observers whose normal thresholds were raised during the experiment stated that when they did hear the tone, it seemed very loud and abrupt. Immediately after a response to a sound which was far above the normal threshold, each of these individuals would respond to tones on the normal threshold and some time had to elapse before he would not react to such stimulation.

Interpretation of Results

To give an exact reason why the auditory threshold changes during states of abstraction is not an easy task. The work done in this investigation is too elementary to draw any definite and sharp-cut conclusions. At this time, it will have to suffice merely to give opinions and conjectures. We can only speculate as to why some observers responded

to subliminal stimulation and others required sounds above the normal threshold to arouse them.

The preliminary practice meager as it was gave the subjects a certain attitude or set. This set carried over into the period of abstraction with four of the subjects so that the responses were made without the awareness of the observer and to stimuli that were below the normal threshold. We cannot be sure whether the difference in response was due to increased acuity of the receiving apparatus or to a facilitation in the nervous conduction brought about by the abstraction. If it were due to increased acuity, it seems that all observers should have reacted alike. If it were due to nervous set, then it is easy to conceive why some acted in one way and some in another. Questioning elicited the confession that those who required a stronger stimulus than their normal threshold tried not to listen for the stimulus; which means that they were set against it and so they required a more intense stimulus to break through this negative set. Those who obeyed the instruction and maintained the set to respond while they abstracted were enabled to react to a stimulus below their normal threshold.

This experiment indicates that the so-called 'automatic' activities that occur in dissociation need not be well practiced habitual responses. The important requirement seems to be that the subject accept the directions of the experimenter. The difference in response may be due to more or less readiness to accept the directions as given, or may be due to the fact that different individuals interpret the same directions differently and so maintain a different set.

Future Research

The sense of audition presents only one field to study changes in thresholds in states of abstraction. The visual and cutaneous senses are especially susceptible to a study of this sort and should yield as fruitful results as have been obtained in this investigation.

It would be interesting to compare the thresholds of the various senses during 'crystal gazing' with those in a hypnotic

state. This could be quite easily studied with pathological cases.

Another phase of the problem which would undoubtedly lend itself readily to experimental investigation would be the ascertaining of the reaction time in crystal gazing and compare it with that under ordinary conditions.

After more detailed study has been made, it ought to be possible to standardize a test whereby an individual's ability to voluntarily abstract could be measured. If such a test could be devised, it should prove useful in detecting cases of hysteria.

Summary

This paper reports an experimental study of the effect of abstraction on the auditory threshold.

1. It was found that the auditory thresholds of eight of the ten observers changed during 'crystal gazing.'

2. The thresholds of four of the individuals were lowered while the thresholds of the other four were raised.

3. The responses made by those observers whose thresholds were lowered were without awareness.

4. When the individuals whose thresholds were raised during the experiment did hear the stimulus, it seemed loud and very abrupt.

5. It has not been sufficiently determined whether the responses to subliminal stimuli were due to increased acuity of the receiving organ or to the neural set involved, although the facts seem to point to the latter interpretation.

THE SELECTIVENESS OF THE EYE'S RESPONSE TO WAVE-LENGTH AND ITS CHANGE WITH CHANGE OF INTENSITY

BY I. A. HAUPT

Longwood Circle, Roland Park, Maryland

Introduction

The present study marks an attempt to deal quantitatively with the selectiveness of the response of the eye.[1] The eye shows selectiveness of response in three ways: (1) to wave-length; (2) to intensity; (3) to time of exposure of light. That is, both in its achromatic and its chromatic response the eye is unequally sensitive to wave-lengths of light; its responses, particularly its chromatic responses, are a complicated function of intensity of light, and they change irregularly with the time of exposure to light. In the latter regard the eye is very exceptional indeed as compared with the physical instruments. With increase of time of exposure, its response increases rapidly and irregularly, varying with the wave-length and the intensity of light, until a maximum is reached and then decreases, at first rapidly and then more slowly approaching zero as a limit. In short, the responses of the eye are a highly complicated function of three variables, the complication being much greater for the chromatic than for the achromatic response.

These peculiarities of behavior are supposedly evolutionary adaptations in the interest of the eye as an organ of seeing. They complicate and render difficult, however, many technical uses of the eye. From both points of view it is important to know them quantitatively and minutely, in order, first, that lighting and other important factors in our working environment may be most effectively adapted to the service of the eye and, second, that the most effective use may be made of the eye itself and in connection with instruments

[1] While the experimental part of the work was done in the Psychological Laboratory of Bryn Mawr College under the direction of Professor C. E. Ferree and Dr. Gertrude Rand, the author alone is responsible for the conclusions.

designed to extend and amplify its powers in the work of the arts and sciences. In the general subject of optics the emphasis given to the purely physical side has been entirely disproportionate. A great deal of time, money and energy have been expended on the study of light and physical optics, and little on physiological optics; yet both of these subjects are ultimately useful over a wide range of their application only in so far as there is knowledge of physiological optics. Thousands of dollars have been spent in the production of lights and lighting with never a question raised as to what the eye needs with regard to the factors of composition, intensity and distribution. This is but one example selected from a number. Along many lines of applied optics further advancement must come first from the physiological side.

Little is known in a quantitative way of the chromatic sensitivity of the eye or its variation with the factors wave-length, intensity and time of exposure. In prior studies in this laboratory all of the above aspects of the selectiveness of the achromatic response of the eye have been subjected to quantitative determination. No quantitative work has been done, here or elsewhere, however, so far as we know, on the selectiveness of the chromatic response. While the chromatic response has not in general the utility and practical importance of the achromatic response, still in proportion to what is known there is perhaps a greater practical need at this time of a detailed knowledge of the chromatic than of the achromatic powers and peculiarities of the response of the eye. It has been the purpose of this study to inaugurate a series of systematic investigations of this neglected phase of physiological optics.

It was considered desirable to conduct the investigation with foveal stimulation, since foveal vision is perhaps the greater and more important part of our seeing. Since the stimulus field had to be divided into standard and comparison halves, it was desirable to work with as large color fields as possible. In attempting to satisfy both of these conditions one is confronted with some difficulty because of the con-flicting data and beliefs as to the exact size of the fovea.

According to Kollicker's[1] measurements, for example, the foveal depression is from .18–.225 mm. in breadth, the visual angle equivalent of which is .42–.92 min. These measurements are quoted and accepted by Helmholtz.[2] J. G. McKendrick says:[3] "The yellow spot has a horizontal diameter of .2 mm. and a vertical diameter of .8 mm. and it corresponds in the visual field to an angle of from 2–4 degrees. The fossa (*fovea centralis*) has a diameter of only .2 mm. which makes the angle ten times smaller." Koster[4] measured four cases and gives the dimensions of the rod-free area as .44–.90 mm., with .5 mm. as the most probable average diameter. Schaeffer[5] says "most observers give the foveal depression a diameter of 0.2–0.4 mm. or of 0.75–1.50 degrees." Tscherning[6] accepts and quotes these values. König[7] assigns 55–70 min. as the angular measurement of the apparent fovea of his right eye.

Howell [8] offers the following explanation of the discrepancies of the different observers: "In some cases the measurements are made from the bottom of the depression, the fundus, in others from edge to edge. . . . In the center of the fovea lies a smaller, very shallow depression spoken of as the foveola. While measurements on preserved specimens give the diameter as .2–.4 mm., ophthalmoscopic examination seems to indicate that in the fresh state it may be larger." The latter statement is in agreement also with Quain.[9] In the 'International System of Ophthalmic Practice' [10] one finds the statement that the fovea and the macula are identical. Foveola is the term applied to the depression. This is situated slightly outward and downward from the center of the papilla. The *Fundus Oculi* defines the limit of exact

[1] Kollicker, A., 'Verh. der Wurzb. med. Ges.,' III., p. 316, 1852.
[2] Helmholtz, 'Physiologische Optic,' I. ed., p. 21, 1867.
[3] J. G. McKendrick, 'A Textbook of Physiology,' Vol. II., p. 631, 1889.
[4] Koster, *Arch. f. Ophth.*, 1895, XLI., part 4, p. 1.
[5] Schaeffer, 'A Textbook of Physiology,' II., 1900, p. 1103.
[6] Tscherning, 'Physiological Optics,' 1904, p. 36.
[7] König, 'Gesammelte Abhandlung zur Physiologischen Optik,' 1903, p. 355.
[8] Howell, 'Textbook of Physiology,' 1907, pp. 314–315.
[9] Quain, 'Textbook of Physiology.'

vision by the macular ring 1.75–2 mm. in diameter or 4.5–5 degrees visual angle. Parsons describes the foveal region as elliptical, horizontal axis 0.3 mm., vertical axis 0.2 mm. The angular measurements of the fovea centralis are given as 55–70 minutes. The rod-free area subtends an angle of 3° 3′ and the macula 4° 12′. In recent experimental work Ives chooses a visual angle of 2° as falling well within the fovea, but gives no authority or citation in justification of his choice. The following table will serve as a summary of the more important estimates.

TABLE I

ESTIMATES OF THE SIZE OF THE FOVEA

Name	Angle	Diameter
Kollicker	42′– 52′	.18–.225 mm.
Koster	1° 40′–3° 26′	.44–.90 mm.
McKendrick	42′	.2 mm.
Schaeffer	42′–1° 30′	.2 –.4 mm.
Tscherning	42′–1° 30′	.2 –.4 mm.
König	55′– 70′	
Howell	1° –1° 30′	.3 –.4 mm.
Ives	2°	

The color field used by us in this work was a circular opening in the screen between the focusing lens and the eye, at a distance of 270 mm. from the eye. The visual angle subtended was 1° 55.8′.

II. EXPERIMENTAL

A. Purpose of the Investigation

In general the response of the eye to colored light takes the following course: at low intensities it is sensed as colorless; at a certain higher intensity, varying with the wave-length and the individual eye, the chromatic response is aroused. With further increase of intensity there is a more or less regular increase in the chromatic component of the sensation until a maximum is reached, the value of this component and the point at which the maximum is reached again varying with the wave-length and, within certain limits, with the individual eye. Still further increase of intensity results in a decrease in the chromatic component until a

point is finally reached with very high intensity at which the sensation is again colorless or approximately so. The change of intensity results also, varying with the wave-length of the stimulus, in changes in the hue of the color sensation.

The present study includes the determination of the following points:

1. The amount of energy needed to give the threshold of color at seven points in the spectrum. These results enable one to compare the chromatic sensitivity to wave-length at the threshold of sensation and to plot a chromatic visibility curve at these minimum intensities.

2. The sensation is laid off in just noticeably different steps from the threshold to the maximum of chromatic response and as far beyond this point as produced any further changes in saturation or as the limits of the apparatus would permit. A comparison of the increments of light energy required to produce these just noticeable changes for any one of the stimuli reveals the selectiveness of the eye's chromatic response to intensity for that range of wave-lengths. A cross comparison between the series for the different stimuli at points representing an equal number of just noticeable differences from the threshold of sensation represents the selectiveness of response to wave-length and its change with change of intensity.

3. The point of maximum response has been determined for each of the stimuli used and for several observers and the amount of light required to give this response has been measured both radiometrically and photometrically. The wave-length and the radiometric specification fixes the point in absolute terms, the wave-length and the photometric specification in terms more in conformity with those used in lighting and other subjects in which practical applications are made. Another important feature of these determinations is the knowledge they give of the relative power of response of the eye to the different wave-lengths. That is, the response is laid off in just noticeably different steps until a maximum is reached. The total power of response may in each case be rated directly as the number of steps from

zero to maximum. To those who believe that the difference threshold may be taken as a unit in terms of which to rate sensation intensities this estimate should be considered correct within the limits of experimental errors: to those who do not believe that the just noticeable difference represents equal steps or amounts of response the rating can be considered as only approximate, but as nearly correct as possible in the psychophysical procedure. Total power of response is a new feature in the comparative study of the characteristics of response of the sensory mechanism. A correlation between the total power of response and sensitivity is possible and even probable, but by no means *a priori* necessary.

B. Apparatus

It is obvious that if the variation of the chromatic component is to be traced in just noticeable difference steps from minimum to maximum and back again to minimum we must be able to produce two stimuli independently variable in intensity over a wide range of intensity, identical in composition, and as nearly homogeneous as to wave-length as possible. We must be able also to present this stimulus to contiguous parts of the retina, and to vary each in turn by just noticeable difference steps; and to specify the intensities at every point radiometrically or photometrically or in both ways as the purpose of the work may render desirable. The greater part of the apparatus used for accomplishing this purpose has been in use in Bryn Mawr laboratory for several years for work on color sensitivity.[1] Only such devices were added as were required to adapt it to the needs of the present study.

A description of the apparatus resolves itself into three sections: I. The spectroscopic system, II. The intensity reduction system, III. The photometric system. In order that the detailed description of the apparatus may be more readily understood, the course of the beam of light is given as follows: the light rays from the source pass through the collimator lens, are rendered parallel, pass through the carbon

[1] C. E. Ferree and G. Rand, Journ. Exp. Psych., Vol. I., No. 3, 1916.

bi-sulphide prism and are focused in the plane of the analyzing slit by the objective lens. Beyond the analyzing slit the diverging rays are again rendered parallel by an auxiliary collimating lens, making it possible for reduction purposes to intercept the entire beam of light with the sector disk. Finally the rays are focused directly on the eye with an auxiliary focusing lens. Figure I. represents schematically

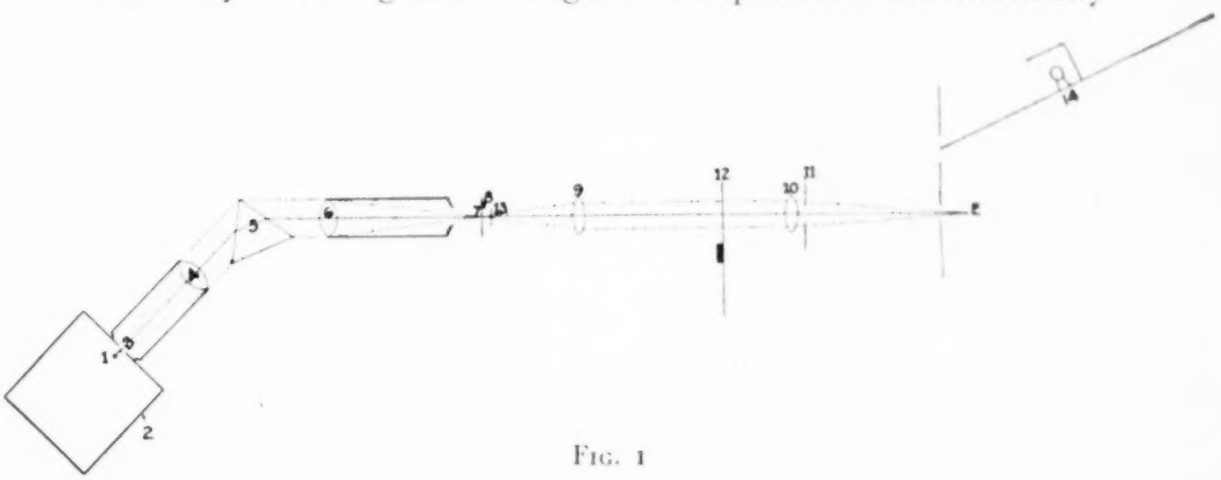


FIG. 1

the arrangement of the apparatus; Figure II. is a photograph of the apparatus as it was actually set up for use.

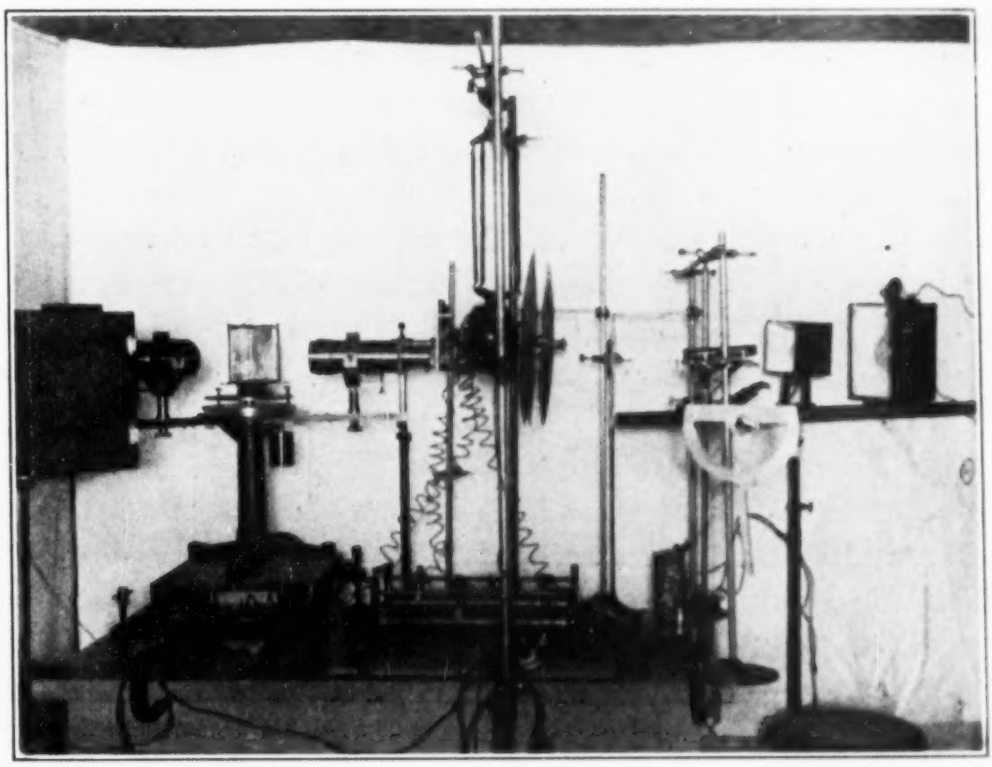


FIG. 2

I. *The Spectroscopic System.*—In detail the spectroscopic system consists of the Nernst filament (1),[1] a special light-proof box (2), made of sheet iron, 15 x 28 x 20.5 cms., with a light-proof ventilator in back and on top. The box is fitted directly on the collimator tube and encloses the Nernst mounting and the collimator slit. It is provided with a door opening all of one side, thus permitting easy manipulation and adjustment of the filament and slit. The advantage of such a box is its efficiency in reducing the amount of stray light without the use of cloths and screens. Such a box can easily be constructed by any laboratory mechanician at very little expense.

The collimator slit (3) is 11 mm. long and is set at a constant width of 2 mm., allowing a maximum flux of light from the filament to illuminate the surface of the prism. The collimator lens (4) is a Zeiss triple achromat, 60 mm. diameter, 180 mm. focal length. The prism (5) is of the hollow glass type, filled with CS_2, 100 mm. high, with a refracting base of 85 mm. and a refracting angle of 60°. With the exercise of a reasonable amount of precaution to keep the CS_2 free from impurities and to maintain a constant temperature in the room this prism has given satisfaction. Emphasis should be placed on the importance of maintaining a uniform temperature in the room when using a CS_2 prism. If this is not done, considerable annoyance is caused by the need frequently to check up the wave-length falling on the analyzing slit. Large changes in temperature cause a change in the refractive index of the CS_2, thus causing a shift in the wave-length falling on the analyzing slit.

The objective lens (6) is another Zeiss triple achromat, 60 mm. diameter and 240 mm. focal length. Both the collimating and the objective lens are mounted in brass tubes, painted black on the inside. The entire beam passes through these, but stray light reflected from the surfaces of the lenses, etc., is to a considerable extent absorbed by the walls of the tubes.

[1] *Ibid.*, page 253.

The analyzing slit (7) is placed in the plane of the spectrum focused by the objective lens. It is set at a constant height of 4 mm. By observation this gave the maximum size image that would fall within the normal pupil. The width of the slit is .4843 mm. The slit is mounted on an oblong brass frame, 12 cms. long and 6.5 cms. wide. On the side nearest the prism are attached holders into which are inserted small gelatine filters especially selected to increase the purity by limiting the light transmitted to the range of wave-length selected for investigation. It is very important in all work on color sensitivity which is meant to be quantitative that light as nearly homogeneous as to wave-length as possible be employed. The presence of alien wave-lengths affects the determination of chromatic sensitivity in 2 ways: (*a*) through the physiological inhibitions and interactions it decreases the amount of color response; (*b*) it increases the value of the energy measurements. On the other side of the brass frame, away from the prism are grooves into which is inserted for radiometric purposes the linear thermopile (8) with its receiving surface facing the direction of the slit.

The energy measurements were made with a linear thermopile having bismuth and silver couples, designed by W. W. Coblenz of the Bureau of Standards. A Paschen small coil galvanometer constructed especially for the thermopile was employed and suitable auxiliary apparatus. This group of apparatus was designed and constructed by request for this laboratory for quantitative work on color sensitivity. A detailed description has been given in a previous article.[1] The apparatus is so planned that energy measurements may be made at the objective slit, at the stimulus opening in the screen situated just in front of the focusing lens and at the eye. A description at one of these places, namely at the objective slit, sufficient to show the method employed is given in the above-mentioned article. It was decided in this study to specify the energy density (*i.e.*, the energy per square milli-

[1] *Psych. Rev. Monog.*, 1917, XXIV., 'Radiometric Apparatus for Use in Psychological Optics,' C. E. Ferree and G. Rand.

meter) at the analyzing slit and at the eye. If desired the energy density at the stimulus opening can be computed from the data given inasmuch as the dimensions of the stimulus opening are given and all of the light from the opening enters the eye. Of these specifications the energy density at the stimulus opening sustains perhaps the most direct and most nearly comparable relation to the energy density of the image formed on the retina, the actual stimulus for the sensitive elements.

As has been stated the apparatus has been so planned that the energy measurements may be made at the eye. However, the intensity of the beam from the objective slit is greatly reduced by the comparatively small stimulus opening needed for work within the fovea. Because of this reduction it is a matter of some difficulty to make the measurements of the small amounts of energy represented in the shorter wave-lengths with a satisfactory degree of precision. The energy was measured directly for the red, both at the analyzing slit and at the eye. In making the measurements the full height of the slit was used and all of the energy emitted from the slit measured and also in the image formed in the plane of the pupil of the eye. A factor was thus obtained which could be applied to all of the wave-lengths at the analyzing slit to reduce them to the proper value for the image in the plane of the pupil. To give the actual value entering the eye, however, a further reduction was necessary. That is, in order to insure against variations between values measured or computed at the pupil and the actual amount of light entering the eye, the light entering the eye had to be made independent of variations in the size of the pupil. Independence of change in the size of the pupil was especially needed in this work because of the large variations in the intensity of the light used. Such control is very easy to secure with the means of presenting the light to the eye used in the apparatus. All that is needed is to keep the image that falls on the eye of a constant size and smaller than the pupil throughout its entire range of variation in the given series of experiments. Not only can

the variation be determined in preliminary experiments as a guide to the size of the pupil, but the image itself can be compared with the size of the pupil at every observation. This control of size of image on the pupil is secured by a very convenient attachment for the objective slit by means of which the length of the aperture of the slit may be varied by ½ mm. steps. Space will not be taken here for a detailed description of this device. In brief it consists of two knife-edge jaws moving in the vertical, operated by means of a ratchet and spring. Still finer control could be secured of course by means of a micrometer screw. Constructed in this latter form the device would be available as a means of producing finely graded changes in intensity. The dimensions of the image chosen, the selection having been based on a long series of observations under the conditions of work employed, were 3.475 mm. x .96 mm. The size of this image and the image measured by the thermopile were compared by measuring on a micrometer comparator the images formed on photographic plates mounted in the plane of the pupil of the eye. A comparison of these dimensions gave a correction factor by means of which the energy measured was reduced to the energy entering the eye.

To serve the purpose of the investigation the method of presenting the colored light to the eye had to fulfill the following requirements: (1) a method was required which would give the effect of a homogeneous surface or field of suitable size and shape which could be imaged on the retina; (2) the apparatus should be available for use in the light as well as in the dark room; (3) provision had to be made for controlling the brightness of the field surrounding the color, also of the pre-exposure of the surface to which the eye was exposed immediately preceding the stimulation to color; (4) the method of presentation had to be such as to permit of no admixture of light from the room with the range of wave-lengths needed for the stimulus; (5) it had to be as little wasteful of light as possible else a sufficiently high range of intensities could not be secured. In order to present the stimulus in compliance with the above plan, the rays of light

emitted from the objective slit (7) are first rendered parallel by lens (9), Fig. 1, placed at 150 mm., its focal length, from the objective slit of the spectroscope, and then focused by lens (10), focal length 270 mm. directly on the eye at *E*. The focusing lens (10) is mounted 20 cms. from the auxiliary collimating lens (9) in order to permit of the easy introduction of the rotating sector disk (12) used as a means of reducing the intensity of light.

II. *The Intensity Reduction System.*—As has been stated above, if the chromatic response of the eye is to be traced from minimum to maximum by just noticeable difference steps, it is necessary to present to the eye two contiguous fields of color, one to be used as standard to which the other may be compared. Furthermore, we must be able to reduce the intensity to the threshold and to vary each field independently by small amounts for each step in the series. The range of variation must therefore be from minimum to maximum of the chromatic component of the eye's response, and beyond, in order to be able to determine accurately the position of the point of maximum saturation.

The primary reduction was effected by means of three neutral gray gelatine filters, mounted between glass, 2.5 x 2.5 cms. These filters, furnished by the Eastman Kodak Company, have their densities specified by the research laboratory of the Company. By means of the formula

$$\text{Density} = \log \frac{1}{\text{Transmission}}$$

the transmission for each filter was calculated. The densities and their transmission values are:

Filter	Density	Transmission
No. 1	1.3	.050118
No. 2	2.0	.01
No. 4	4.08	.000083
No. 1 and No. 4	1.3 and 4.08	.00000416
No. 1 and No. 2	1.3 and 2.0	.00050118

A special filter holder was designed so that two filters could be inserted in combination. The filters in their holder (13)

were placed in front of and close to the analyzing slit, so that the area of the gelatine used should be as small as possible, insuring maximum uniformity of transmission.

Further reductions and fine variations in intensity were effected by means of sector disks, designed especially for J.N.D. work.[1] In brief the set consists of four pairs of disks, with a radius of 19.5 cms., cut from sheet aluminum and painted a dull black. The first pair, giving a range of variation of total open sector from 0°–180° is constructed with a total closed sector of 180°. In the second pair the breadth of total closed sector is 90° and the range of total variation of opening is from 180°–270°. In the third pair the breadth of the closed sectors is 45° and the range of aperture from 270°–315°. In the fourth pair the breadth of the closed sectors is 22.5° and the range of aperture is 315°–337.5°. For J.N.D. work this set is supplemented by single disks of the same breadth of sectors, but of lesser radius. These were made with a radius of 17 cms., thus leaving a margin of 2.5 cms. between the edges of the two sets of disks. The two sets were so adjusted that the edge of the inner disk bisects the stimulus field, thus giving two contiguous fields, one of which was used as standard to which the other was compared. A special protractor,[2] designed for use with these disks, made it possible to measure the open sectors to ¼°.

By using the gelatine filters in combination with these disks, the objection often raised against the use of J.N.D. disks, namely the difficulty of measuring small amounts of change accurately, was to a large extent obviated. Only in a few instances was it necessary to measure less than 1°. The experimental results show in these instances discrepancies that may be ascribed to the errors in measuring. These errors might have been reduced if more filters had been used, but they could not have been foretold until the final calculation of the entire data was complete. To eliminate these experimental errors would necessitate several repetitions of the entire experimental series, and averaging the results.

[1] Jour. Exper. Psych., Vol. I., No. 3, 1916, p. 271.

[2] *Ibid.*, p. 271.

The improvement in the data obtained by such a procedure would hardly justify the long and tedious labor of repeating a J.N.D. series from minimum to maximum for each color several times. Where these discrepancies do occur they are so obvious as not to detract from the value of the general conclusions which are to be derived from these data.

To bridge the gap from one filter to the next, the sectors were set to reduce the amount of light by the same amount as the filter had reduced it. For example, the threshold for red was found with a filter transmission .00000416, sector disk value 33° total open sector. By varying the value of the open sector as was needed, four J.N.D.s in saturation were found requiring a change in open sector to 360°. Filter No. 1 was then removed (transmission .050118) and the value of the open sector reduced until the value of the light transmitted by the sector and the filter No. 4 (transmission .00083) was the same as had been transmitted by filters No. 1 and No. 4 and 360° total open sector. That is, filter transmission multiplied by the sector value = new filter transmission multiplied by the new sector value or

$$.00000416 \times 360 = .000083 \times (X),$$
$$(X) = \frac{.000083}{.0014976}$$
$$= 18°.$$

Thus the total open sector value of 18° with filter No. 4 reproduces the intensity transmitted through filters No. 1 and No. 4 and a total open sector value of 360°. Just noticeable difference steps were again determined until the limit of range with filter No. 4 was reached. Now filters No. 1 and No. 2 were substituted. The equation becomes:–

$$.000083 \times 326° = .0050118 \times (X),$$
$$(X) = \frac{.027058}{.0050118}$$
$$= 54° 15'.$$

Settings were made to the nearest quarter of a degree.

III. *The Photometric System.*—The photometric apparat

served two purposes in this investigation: (*a*) In one part of the investigation it was decided to make the determinations with the immediately surrounding field of approximately the same brightness as the colored stimulus in order to eliminate the effect of physiological induction in the saturation and hue of the color. For this the photometric apparatus provided both the illumination and the means of controlling the intensity of the illumination needed. (*b*) At the point of maximum saturation both a photometric as well as a radiometric determination of the colored light was wanted, *i.e.*, the radiometric determinations were needed as a basis for the quantitative estimations of the selectiveness of the eye's response and the photometric determination in order to provide a specification of the intensity of maximum saturation in terms commonly used in colorimetry and all practical applications of physiological optics.

In order to secure control of the brightness of the surrounding field it was necessary to provide *as surrounding field a surface of the brightness equaling point by point* the brightness of the colored stimulus as its intensity was changed from threshold to maximum. This was done by selecting for the surrounding field neutral pigment papers approximately graded as to reflection coefficient and by varying the intensity of the light falling on these surfaces by amounts needed to give the brightness match. The selection of the pigment surfaces was made from a series of Hering standard gray papers, graded from 1–50. The needed change of illumination of the surrounding field was secured by means of a lamp moving along a photometer bar. This bar was supported on floor stands with extension uprights to allow of adjustment in height. The range of movement provided by the bar was two meters. The lamps used were a type *C* automobile lamp, 24.73 c.p., operated on a storage battery at .8 amp., and a 100-watt type *C* lamp operated at .85 amp. on the regular line current.

C. Method of Determination.

To render the eye approximately uniformly sensitive a 15-minute period of dark adaptation was taken before each period

of work. This condition of sensitivity was maintained throughout the series, as far as compatible with change of intensity of stimulus light, by short exposures (2 to 3 seconds) and frequent rest periods. The method of limits was employed in making the determinations. Several weeks of practice work preceded the final determinations.

As has been stated above, the gross reduction in intensity was made with the neutral filters and the final determinations of the J.N.D. steps were made with the sector disk. The value of the open sector was measured with the vernier protractor and settings were made to the nearest ¼ degree. For the J.N.D. determinations the outside disk was moved so as gradually to increase the value of the open sector until the right half of the field appeared just noticeably more saturated. For the descending series the outside sector disk was opened still further, giving more than a just noticeable difference in saturation, and then gradually decreased until the field appeared uniform. The average of the series of determinations was taken and both sector disks set at this value for the next J.N.D., etc., until a point was reached where the lighter field appeared less saturated. The point of maximum saturation was determined for seven points in the spectrum by six observers and the intensity specified both in radiometric and in photometric terms. The determinations of the J.N.D.s were continued beyond the point of maximum saturation until no further change of saturation with change of intensity could be detected or to the limit of intensity of the apparatus.

The first series (*A*) was made in the dark, with a dark surrounding field, and the second series (*B*) with a surrounding field of approximately the same brightness as the stimulus.

The monochromatic lights used for this investigation were bands from the following regions of the prismatic spectrum: 655 μμ, 616 μμ, 580 μμ, 553 μμ, 522 μμ, 488 μμ, and 463 μμ. The wave-lengths transmitted were checked up every 3 or 4 determinations with a Hilger direct vision spectroscope.

Table II. gives the energy density of these lights at the analyzing slit and at the eye.

TABLE II

Wave-length	Energy per Square Mm. in Watt × 10^{-8}	
	At Analyzing Slit	At the Eye
Red 655 μμ	7656.81874	23.8776
Orange 616 μμ	2679.88621	8.537
Yellow 580 μμ	1196.5544	3.731
Y. Gr. 553 μμ	348.46526	1.0867
Green 522 μμ	287.24839	.89544
Bl. Gr. 488 μμ	141.2697	.41405
Blue 463 μμ	131.85172	.411

The energy value for each J.N.D. step was obtained by reducing the total energy for the maximum intensity at the eye to the fraction of the total light transmitted to the eye, multiplying first by the per cent. transmission through the neutral filters and finally by the per cent. transmission through the open sector for each step.

D. Discussion of Results

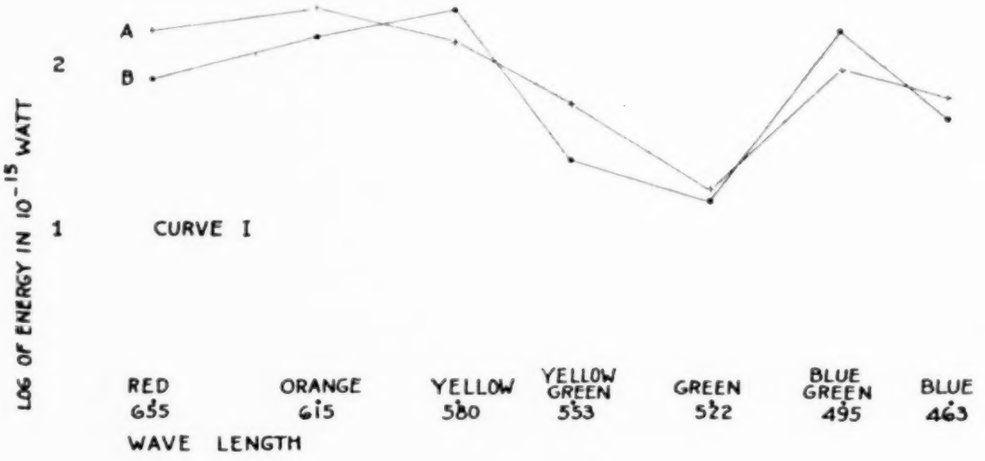
The selectiveness of the eye's chromatic response to wave-length and its change with change of intensity of light may be demonstrated by plotting the amounts of energy required to arouse equal amounts of chromatic sensation for different groups of wave-lengths. That is, we plot the amounts of energy required to arouse the threshold, the fifth, the tenth, etc., J.N.D. to the maximum. At any one of these cross-section points, the relation between the energy quantities for the different wave-lengths demonstrates the selectiveness of the eye to wave-length at that point in the intensity scale. The manner in which this relation changes with increase of intensity indicates how the eye changes its selectiveness with change of intensity. In Table III. is given the energy of

TABLE III

ENERGY OF CHROMATIC THRESHOLD IN 10^{-15} WATT

	Dark	Light
Red	173.34	91.53
Orange	239.90	158.78
Yellow	154.84	227.96
Yellow-green	63.81	29.77
Green	18.59	16.20
Blue-green	96.71	172.76
Blue	69.50	51.05

the threshold of chromatic sensation at seven points in the spectrum. The results are given for experiments conducted in the dark room as well as for those with the surrounding field of approximately the same brightness as the stimulus. From these data have been constructed Curve I., *A* and *B*.



Here the writer has plotted the log of the energy at the color threshold against wave-length. Inspection of the curves will show that the eye is generally more sensitive under the condition with the light surrounding field than in complete darkness, except in the case of yellow and blue-green. This increased sensitivity with the light surrounding field is due to the absence, under these conditions, of the induced white light over the color field, obviating the inhibitive action of the achromatic on the chromatic.

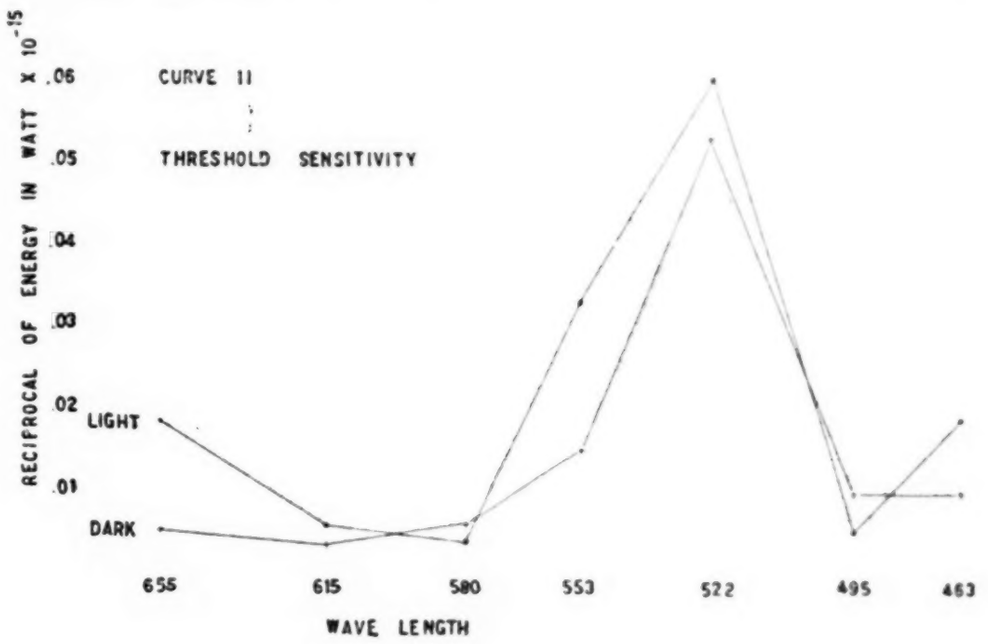
In Table IV. are given the values indicating the color sensitivity of the eye to wave-length at the limen as expressed by the reciprocal of the energy required to arouse the chro-

Table IV

Chromatic Sensitivity at Limen

	Dark	Light
Red	.00576	.01092
Orange	.00417	.00629
Yellow	.00646	.00438
Yellow-gr.	.01567	.03359
Green	.05378	.06173
Blue-gr.	.01034	.00579
Blue	.01431	.01959

matic threshold. These values are plotted in Curve II., *A* and *B*. It is apparent that the sensitivity at this intensity



is greatest for green. This condition obtains throughout the intensity series except at high intensities in the dark, where the values for blue indicate that the sensitivity has shifted towards the shorter wave-lengths. In this connection it may be interesting to mention a fact, observed not only by the writer but also by others in conducting research with spectrum lights, namely, that the effect on the observer of green light from the region of the spectrum around 522 $\mu\mu$ is extremely unpleasant. The writer experienced great discomfort, headaches, watering of the eye, ocular hyperæmia, excessive flow of lymph across the field of vision, especially at moderate and high intensity. The doctrine which is so prevalent that green light is most pleasant for the eye is certainly false as far as spectrum light is concerned. Some discomfort was experienced in working with blue at very high intensities in the dark, but the effect was not nearly so marked.

Table V., *A* and *B*, is so arranged as to give the energy value of each sensation step for the four primary colors. An inspection of these tables enables us to trace the energy value of each J.N.D. as the intensity is increased. We can pick

out the energy required to arouse the fifth, tenth, fifteenth just noticeable difference in saturation for each of the four colors, showing how the selectiveness of the eye's chromatic response changes with change of intensity.

Curve III., *A* and *B*, has been constructed from the data contained in Table V. The writer has plotted the log of the energy required for each J.N.D. of saturation. The number of J.N.D.s are plotted along the ordinate and the log of the energy along the abscissa. Thus, for example, in Curve III., *A*, at the fifth J.N.D. yellow has the highest energy value, red next, then blue and green least, showing that the eye has its greatest sensitivity in the green and the lowest in the yellow at this point in the intensity scale. The horizontal difference between the four curves at any point in the sensation scale indicates the relative sensitivity to wave-length. That is, the eye shows its greatest difference in sensitivity between the red and the yellow. To green and blue the eye is more equally sensitive. As the eye changes its selectiveness to wave-length with change of intensity, the horizontal difference between the curves changes. Beyond

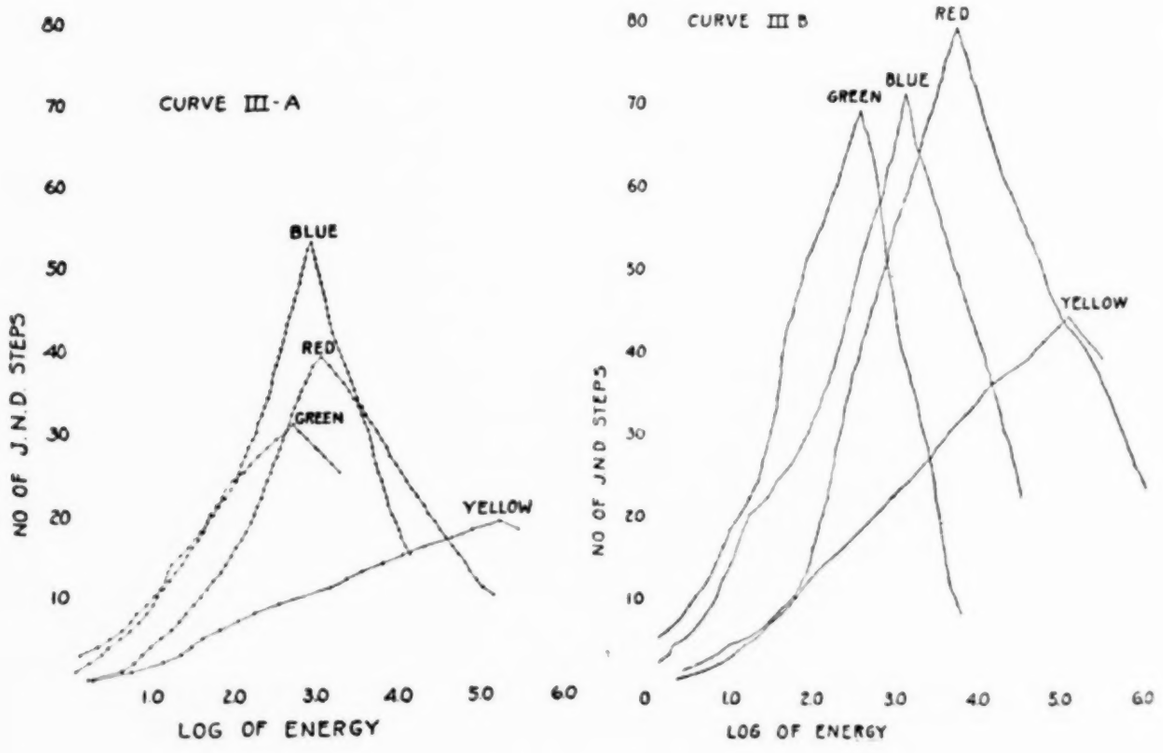


TABLE V

DARK SURROUNDING FIELD

J.N.D.	Red	Yellow	Green	Blue
	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt
1	1.73	1.55	.19	.70
2	4.34	5.69	.31	1.16
3	6.11	14.01	.69	1.80
4	7.85	23.14	1.34	2.52
5	9.81	32.06	2.30	3.06
6	13.58	42.87	3.29	4.30
7	17.91	71.90	4.46	5.57
8	22.57	116.60	5.52	7.05
9	27.21	175.34	6.74	8.90
10	34.19	350.06	9.00	10.41
11	41.30	726.50	11.09	11.91
12	49.51	1,542.47	14.02	13.30
13	59.53	2,389.42	16.88	15.74
14	73.09	3,653.76	20.36	16.50
15	85.77	6,718.89	24.07	18.18
16	97.96	11,956.99	28.36	23.90
17	111.40	21,460.22	33.02	30.16
18	130.79	44,560.22	38.61	37.00
19	149.75	83,670.32	44.70	43.82
20	166.63	M176,167.00	50.96	50.64
21	185.13	315,813.97	58.37	58.62
22	203.05		67.49	66.58
23	222.75		82.41	75.68
24	244.08		97.02	84.52
25	270.21		116.90	97.11
26	299.75		140.55	103.98
27	327.50		172.52	120.67
28	362.00		213.67	136.03
29	393.35		268.20	150.24
30	425.79		354.91	165.12
31	463.43		460.44	180.27
32	508.99		M565.25	195.77
33	560.47		669.52	214.55
34	601.14		819.52	236.17
35	660.09		1,054.92	255.53
36	727.18		1,291.35	276.57
37	815.58		1,609.02	296.52
38	917.25		2,086.15	318.11
39	1,030.23			337.98
40	M1,290.93			357.99
41	1,605.73			390.04
42	1,964.15			419.33
43	2,357.93			447.67
44	2,751.00			475.11
45	3,209.14			510.50
46	3,701.95			544.80
47	4,158.17			578.98
48	5,010.59			616.05
49	5,798.14			651.23
50	6,550.23			694.23

TABLE V (*Continued*)

J.N.D.	Red	Yellow	Green	Blue
	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt
51	7,597.24			741.32
52	8,580.50			791.00
53	9,879.55			849.94
54	11,420.18			907.03
55	13,275.93			M955.50
56	15,524.21			1,015.47
57	17,915.53			1,075.32
58	20,634.21			1,129.43
59	23,579.28			1,198.02
60	28,995.57			1,260.65
61	33,642.96			1,323.49
62	39,208.40			1,391.87
63	45,728.99			1,466.11
64	53,908.61			1,544.54
65	64,680.92			1,625.76
66	75,794.28			1,702.14
67	90,659.13			1,933.95
68	108,464.03			2,106.03
69				2,276.48
70				2,446.12
71				2,675.56
72				2,900.92
73				3,130.37
74				3,359.82
75				3,585.17
76				3,869.93
77				4,154.30
78				4,496.12
79				4,779.70
80				5,064.31
81				5,351.13
82				5,691.20
83				6,032.51
84				6,490.21
85				6,945.09
86				7,508.56
87				8,078.19
88				8,646.12
89				9,555.37
90				10,468.72
91				11,554.50
92				12,701.75
93				14,216.71

TABLE V (*Continued*)

LIGHT SURROUNDING FIELD

J.N.D.	Red	Yellow	Green	Blue
	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt
1	.92	2.28	.16	.51
2	2.74	4.81	.29	.95
3	4.67	8.25	.44	1.40
4	7.25	11.65	.75	1.96
5	9.79	15.64	1.06	2.11
6	17.12	21.17	1.41	3.16
7	24.19	26.30	1.89	3.85
8	31.52	34.46	2.46	4.63
9	39.37	44.34	2.96	5.48
10	51.64	53.87	3.48	6.34
11	62.00	65.87	4.15	7.09
12	69.67	79.99	4.89	7.86
13	78.28	98.31	5.55	8.64
14	87.85	120.00	6.37	9.62
15	94.31	146.56	6.74	10.65
16	101.39	186.20	7.72	11.58
17	107.65	240.52	8.83	12.68
18	115.00	303.24	9.84	13.84
19	123.69	376.41	11.02	15.15
20	131.28	486.31	12.52	16.17
21	140.46	601.12	14.09	18.02
22	147.61	742.28	16.02	23.76
23	156.19	903.91	17.88	29.08
24	163.09	1,118.69	20.26	34.13
25	169.77	1,452.93	22.46	39.24
26	177.78	1,882.02	24.46	47.77
27	185.09	2,270.46	25.55	56.31
28	193.23	2,703.06	26.97	65.53
29	203.07	3,178.82	28.47	73.73
30	212.87	3,843.79	30.00	85.15
31	224.41	4,627.90	31.74	92.15
32	235.82	5,609.35	33.26	101.98
33	247.26	7,083.91	35.02	112.06
34	262.01	8,600.84	36.95	120.25
35	276.75	10,502.55	38.97	134.34
36	291.44	12,406.96	39.95	147.04
37	307.85	14,823.88	41.21	159.74
38	325.86	22,960.67	42.48	172.02
39	349.03	31,354.36	43.67	187.56
40	370.08	40,764.68	45.08	199.88
41	394.75	51,227.62	46.35	212.98
42	422.54	64,309.76	48.36	226.80
43	448.71	79,458.95	49.57	240.84
44	481.23	100,914.09	52.62	253.94
45	520.74	128,617.36	58.13	269.51
46	560.00	M155,793.75	61.11	283.43
47	599.39	188,202.15	65.58	298.28
48	643.48	225,813.09	70.04	317.73
49	670.14	264,547.70	74.52	333.50
50	715.68	316,281.72	78.99	349.48

TABLE V (*Continued*)

J.N.D.	Red	Yellow	Green	Blue
	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt
51	763.60		83.67	368.84
52	817.44		90.91	395.74
53	856.08		99.85	426.62
54	912.04		108.80	460.76
55	962.02		119.23	495.58
56	1,015.34		130.69	531.33
57	1,113.36		141.63	570.71
58	1,211.68		155.04	610.81
59	1,310.10		169.85	655.30
60	1,407.40		184.80	692.19
61	1,506.72		199.68	725.06
62	1,588.90		213.09	767.67
63	1,703.13		228.01	822.01
64	1,838.81		244.42	873.21
65	1,965.09		265.24	925.64
66	2,096.14		286.16	970.71
67	2,227.06		307.00	1,028.03
68	2,390.65		326.40	1,072.10
69	2,387.36		350.10	1,149.37
70	2,784.12		M377.06	1,206.30
71	2,980.40		402.34	1,265.60
72	3,165.60		432.19	M1,325.90
73	3,379.45		463.63	1,400.74
74	3,635.93		490.47	1,474.47
75	3,895.14		520.18	1,544.21
76	4,159.38		545.43	1,622.01
77	4,520.15		570.00	1,691.54
78	4,847.89		591.53	1,757.08
79	5,240.25		616.38	1,933.30
80	5,666.09		652.79	2,105.21
81	M6,123.83		670.00	2,277.23
82	6,515.25		696.04	2,445.28
83	7,040.77		719.86	2,617.19
84	7,538.74		740.67	2,780.36
85	8,057.04		758.51	3,015.53
86	8,646.52		772.77	3,236.84
87	9,335.03		804.73	3,416.74
88	9,988.18		831.55	3,593.14
89	10,742.72		869.88	3,981.91
90	11,452.53		895.71	4,318.72
91	12,275.58		927.01	4,665.06
92	13,135.09		955.26	4,997.53
93	14,279.61		983.60	5,298.20
94	15,394.65		1,020.83	5,821.32
95	16,408.82		1,065.58	6,308.01
96	17,455.74		1,103.02	6,770.26
97	18,799.76		1,162.03	7,283.35
98	20,007.62		1,219.04	7,791.17
99	22,447.47		1,311.18	8,363.51
100	25,218.74		1,400.93	8,932.92

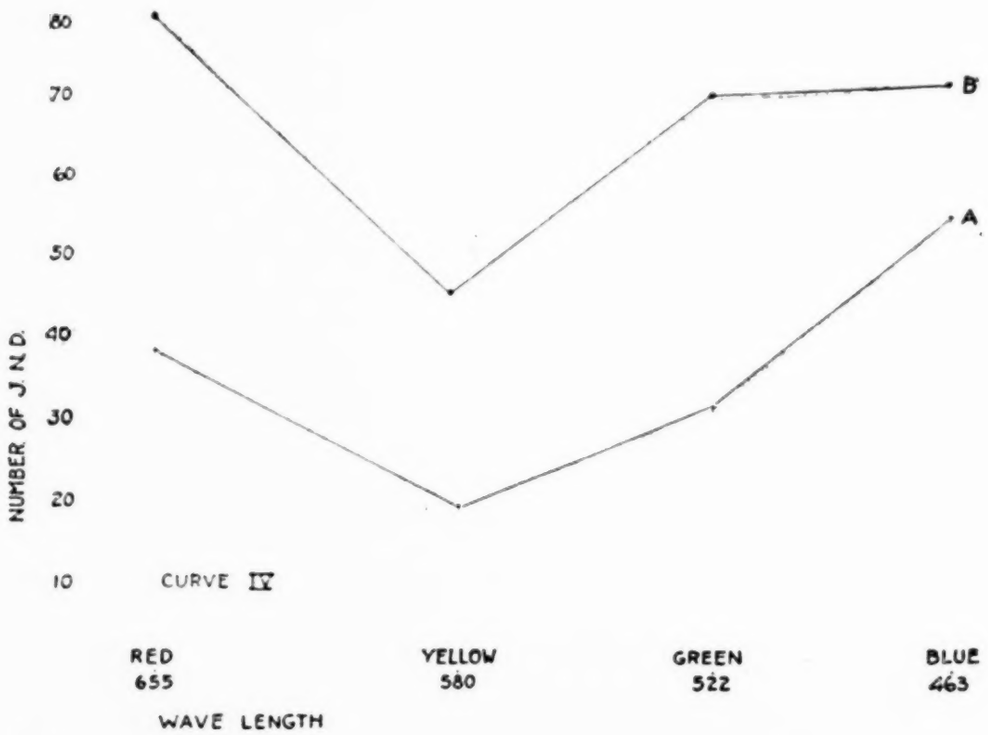
TABLE V (*Continued*)

J.N.D.	Red	Yellow	Green	Blue
	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt	Energy in 10^{-13} Watt
101	28,177.02		1,490.36	9,612.72
102	31,431.17		1,586.92	10,351.59
103	34,572.47		1,698.46	11,142.32
104	38,151.78		1,811.18	12,063.03
105	42,089.00		1,915.26	12,913.88
106	46,014.95		2,034.36	13,823.24
107	50,271.01		2,160.97	14,740.86
108	55,634.02		2,317.91	15,700.05
109	60,103.57		2,437.15	16,780.96
110	64,836.61		2,556.06	17,755.16
111	70,572.77		2,617.06	18,885.48
112	77,594.89		2,742.52	20,025.27
113	84,170.94		2,845.53	21,166.82
114	93,515.40		2,970.08	22,482.10
115	103,488.85		3,107.36	23,780.96
116	124,497.41		3,241.24	25,147.87
117	150,647.98		3,353.05	26,565.11
118	176,844.56		3,433.52	28,216.77
119	202,222.60		3,613.77	29,944.80
120	232,534.08		3,740.63	31,524.47
121	262,012.88		3,845.54	33,235.75
123	291,439.82		3,969.25	34,881.84
124	320,913.92		4,121.30	
125	356,874.44		4,292.22	
126	392,013.86		4,456.04	
127	429,024.88		4,620.42	
128	471,588.63		4,798.35	
129	517,459.79		5,514.02	
130	563,308.85		5,961.45	
131	619,003.09		6,409.53	
132	687,807.41			
133	756,541.00			
134	825,274.62			
135	913,690.50			
136	1,002,119.13			
137	1,091,038.65			
138				
139				
140				

the 25th J.N.D. step the eye becomes less sensitive to green than to blue. This may be due to the greater inhibitive action of the achromatic on the green. It may be noted also that red and green retain their characteristic colors to very high intensities, as indicated by the slope of the curves beyond the maximum. Blue loses its saturation most rapidly, it has the steepest descending curve. The curves of yellow and green appear to have very nearly the same in-

clination. The trend of these results is in agreement with observations made by Helmholtz and others on this point.

From the inspection of these curves we can also see the number of J.N.D.s required to reach the maximum. With the dark surrounding field blue requires 55, red 40, green 32, and yellow 21. With the light surrounding field blue requires 71, red 80, green 70 and yellow 46. If the number of J.N.D.s required to reach the point of maximum saturation may be used as an indication of the degree of saturation at its maximum, as Geissler has suggested, then, in the dark, blue would be the most saturated color, whereas with the light surrounding field red would be. To demonstrate more directly the relative degrees of saturation of the four colors under the two experimental conditions Curve IV., *A* and *B*,



has been constructed. Here the writer has plotted the number of J.N.D.s required to reach the maximum against wavelength. The results are in accordance with the writer's estimate by direct inspection of the rank under the two conditions. That is, blue with the dark surrounding field actually appears more saturated at its point of maximum saturation than the

other colors. With the light surrounding field red appears the most saturated. Yellow has the least saturation under both conditions.

In considering Curve III., *B*, we find that the general trend of the results is similar. The most significant difference is the greater chromatic sensitivity under these conditions, as indicated by the greater number of J.N.D. required to reach the maximum. Furthermore, although the order of sensitivity remains the same (that is, green highest, then blue, red, yellow), the difference between the colors is greater with the light surrounding field than with the dark. This is shown by the horizontal difference, representing the energy value between the points of maximum saturation for the four colors.

That this type of selectiveness of chromatic response to wave-length is characteristic of the eye and not merely an individual peculiarity of response is shown by Curve V., *A* and *B*. This Curve is constructed from data given in Table VI. In the table are given the values of the energy

TABLE VI

ENERGY OF POINT OF MAXIMUM SATURATION IN 10^{-13} WATT

Dark Surrounding Field

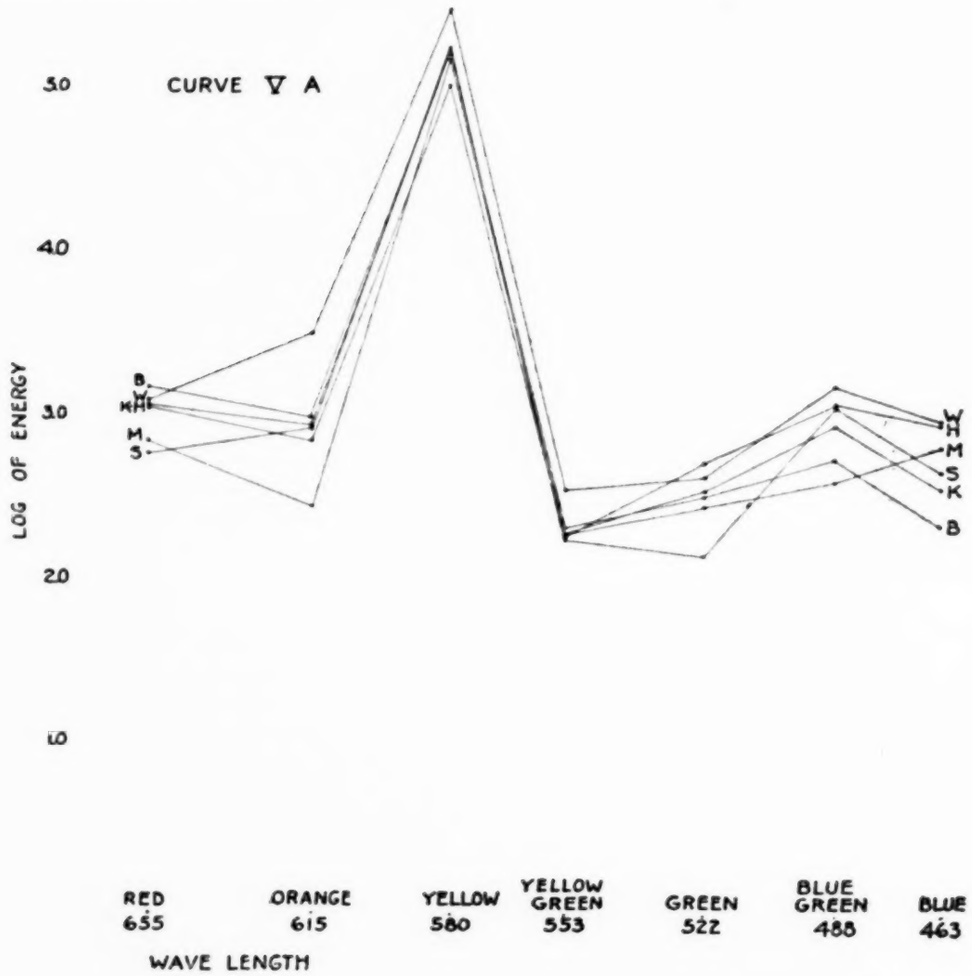
	Red	Orange	Yellow	Y-Green	Green	Bl-Green	Blue
S.....	628.84	881.40	184,673.16	189.68	156.46	1,291.74	503.97
W.....	1,318.07	3,372.17	324,844.52	378.11	452.00	1,648.77	1,024.34
M.....	756.38	301.21	180,018.37	203.35	239.05	439.67	714.17
B.....	1,588.80	1,042.56	177,932.51	216.91	351.42	595.31	233.55
H.....	1,290.93	938.31	174,321.18	198.80	565.25	1,257.46	955.50
K.....	1,191.51	753.01	114,848.20	207.90	368.78	946.61	397.45

Light Surrounding Field

S.....	3,607.89	1,413.39	185,180.37	366.02	223.50	1,529.62	756.78
W.....	5,614.37	6,302.12		55.73	186.27	415.27	515.03
M.....	403.91	521.28	177,932.51	222.98	264.53	519.12	614.43
B.....	1,986.00	684.13	177,932.51	210.94	273.19	635.15	381.05
H.....	6,123.38	556.04	154,132.61	81.33	377.06	1,312.85	1,325.90
K.....	463.48	729.77	180,018.37	96.52	149.03	1,416.84	620.34

at the point of maximum saturation for each of the seven points in the spectrum for six observers. Curve V. was plotted using the log of the energy as the ordinate against

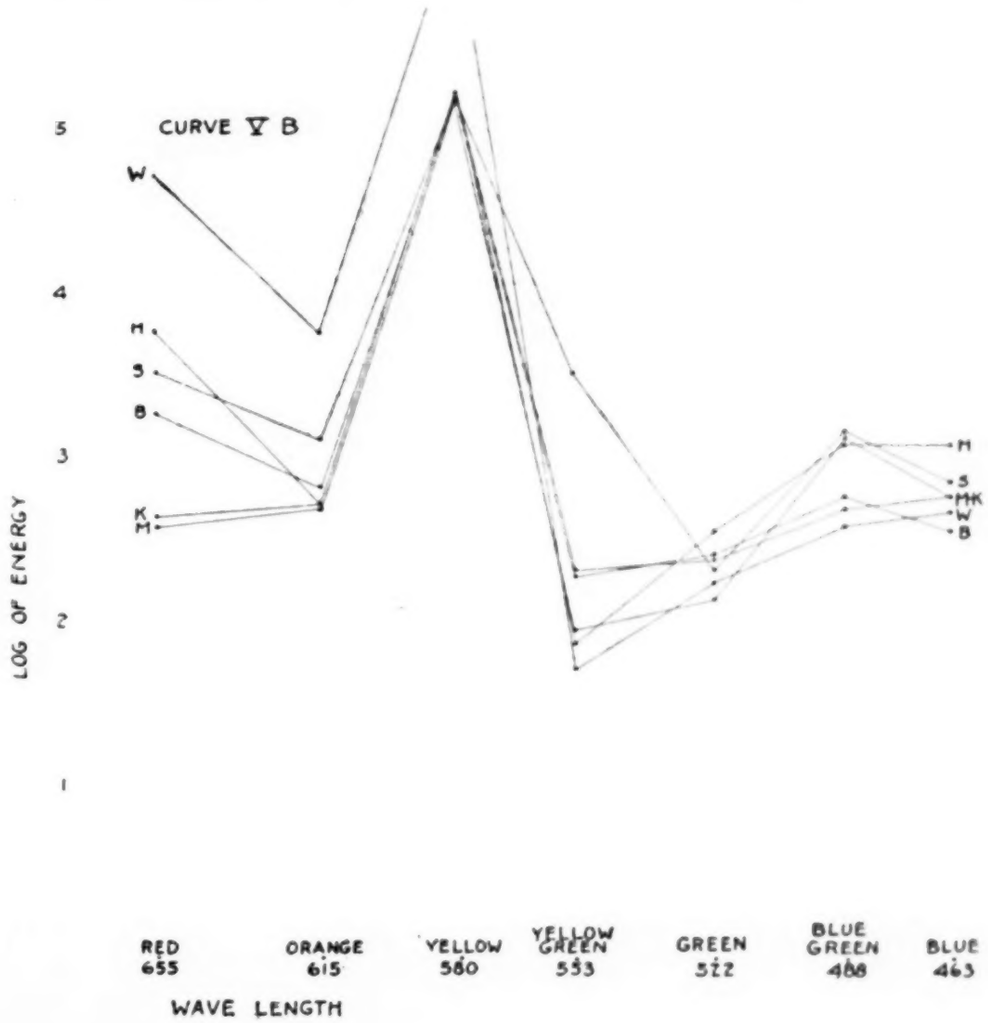
the wave-length along the abscissa. The agreement in the results for the six observers is encouraging. It is closer with the dark surrounding field than with the light surrounding field. For some observers the judgment was easier under this condition. Observer *W*, who, as may be noted in the table, has the highest energy values in the yellow and orange, conspicuously different from the others, may be classed as



erratic. She complained of being seriously hampered in her judgment of color saturation by the vividness and persistence of after-images. No such difficulty was reported by the other observers. The writer's results are included as observer *H*.

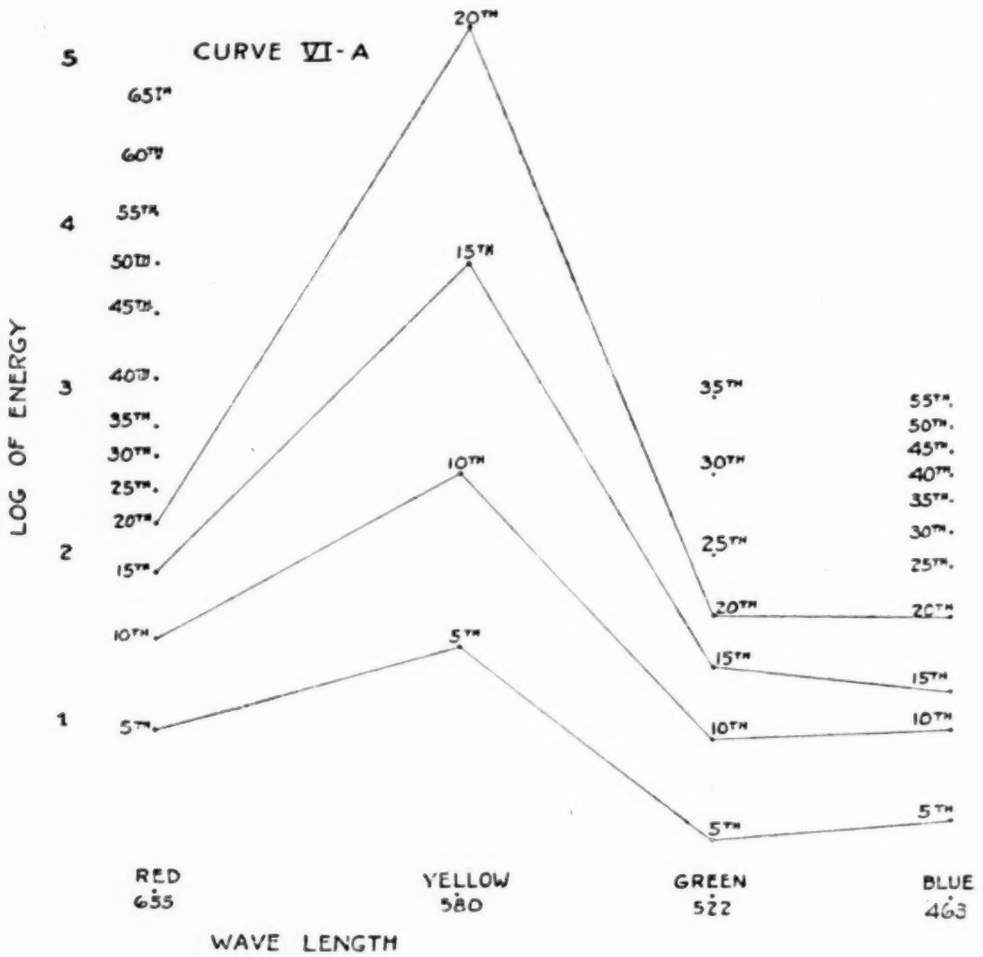
In order to show the change of selectiveness of the eye's response to wave-length with change of intensity we have plotted Curve VI., from the data contained in Table V.

Along the ordinate we have plotted the log of the energy required to arouse the chromatic threshold and every fifth J.N.D. thereafter, for each of the four wave-lengths investigated (abscissa). By inspection of *B*, in the light, we note



that the change in the eye's selectiveness to wave-length with change of intensity is most noticeable in its response to yellow. A marked difference is noted also in the slope of the lines between the values for green and blue, as the intensity increases, particularly between the 20 and 30 J.N.D. This demonstrates again that the eye loses its sensitivity to blue more rapidly than to green, but more slowly to the shorter wave-lengths than to the long. It is interesting to note, with the dark surrounding field, *A*, after the 10th J.N.D. the relative sensitivity to blue and green is actually

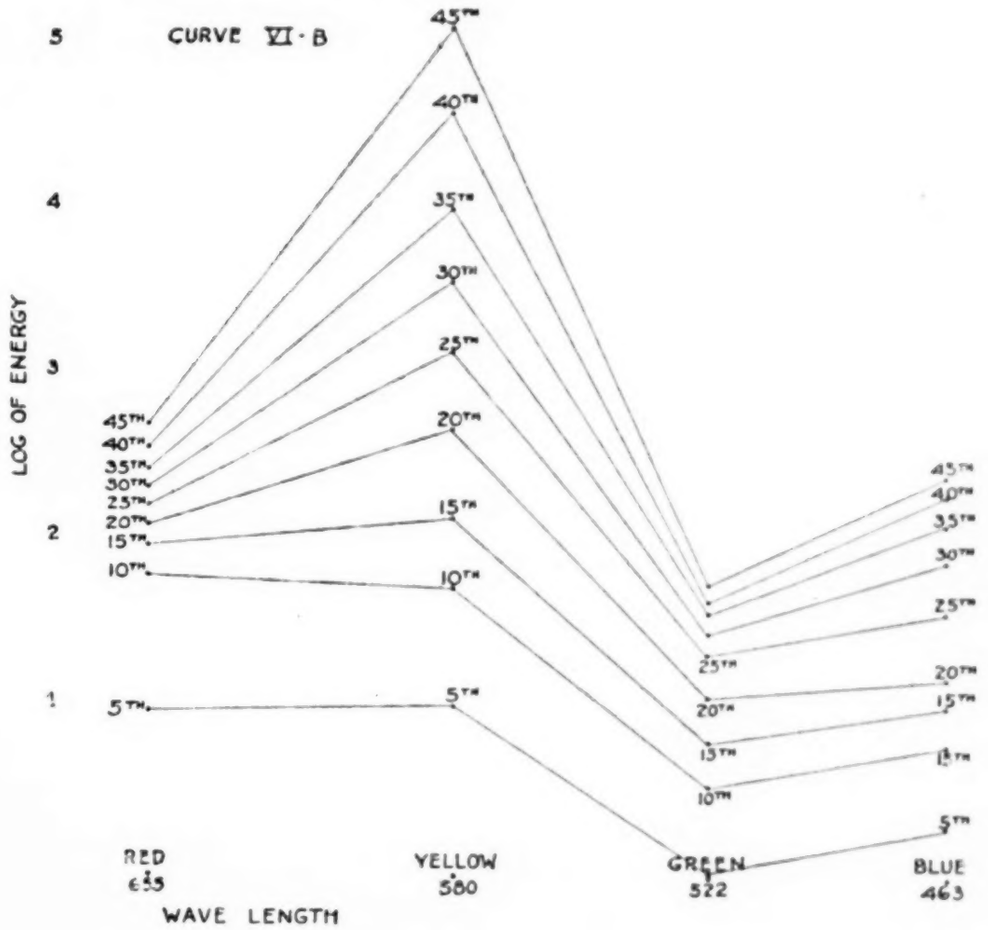
reversed. At higher intensities the eye becomes more sensitive to blue than to green.



In Table VII. are given the photometric specifications of the intensity at the point of maximum saturation. The photometric match was made by the equality of brightness method. The colored stimulus light was set at the intensity to give maximum saturation. A magnesium oxide screen was inserted immediately behind the stimulus opening, dividing the field and at such an angle that the light from the standard photometer lamp fell normally upon the photometric surface. The surrounding field was a screen of Hering White. The standard lamp was moved along the photometer bar to give the brightness match.

In the course of the experiments it was observed that as the intensity is increased, the chromatic sensation aroused

changes both in hue and in saturation. A knowledge of these hue changes is of considerable importance in colorimetry. For example, it is often considered sufficient to give a colorimetric specification of lights at one intensity alone, in spite



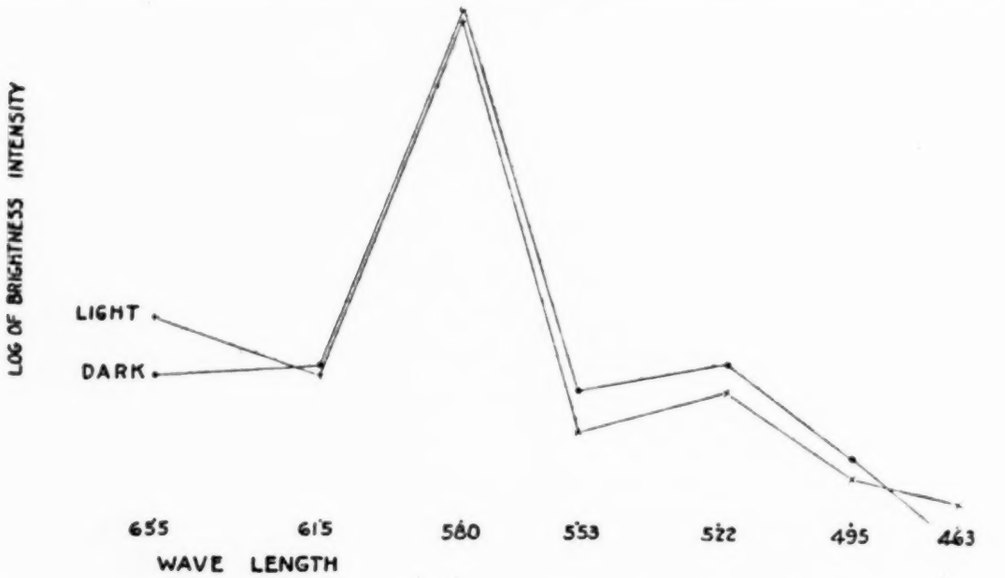
of the fact that both the saturation and the hue of the color changes with change of intensity as well as with the composition. Changes of hue simulating an apparent change in composition of light take place when there is no change in composition, only change in intensity. That is, while specification of the composition of light is independent of intensity, a true colorimetric specification may not, depending upon the method used, be definitive unless it is accompanied by a specification of intensity. In determining the J.N.D. as the intensity of light was increased, the significant changes in hue have been noted, and the points at which they have occurred are specified radiometrically. It was found that in

the work with the dark surrounding field the just noticeable difference for hue is larger than for saturation, hence it was

TABLE VII

PHOTOMETRIC SPECIFICATION OF MAXIMUM IN M.C.

	Red	Or-ange	Yellow	Y-Green	Green	B-Green	Blue
Dark surrounding.....	7.66	8.79	1,318.45	6.39	9.49	2.62	.95
Light surrounding.....	16.87	7.86	1,162.88	3.47	6.21	2.91	1.30



impossible in a progressive series of saturation steps to indicate the exact point in the series where the hue change took place. It is important for all colorimetric interpretation to specify the change under both conditions, because the changes in hue experienced with a light surrounding field are different from those observed in the dark. A still different series of changes is experienced under light adaptation with change of intensity when the surrounding field is lighter or darker than the color field. It was found that at the threshold, with the light surrounding field red appeared as a good red, but at the 10th J.N.D. appeared brownish, at the 30th, brownish-red, not attaining a good red until the 50th J.N.D. At the maximum (80 J.N.D.) the hue may be described as bright scarlet, rapidly acquiring an orange tint (82 J.N.D.), passing through orange pink as the intensity was increased.

Yellow appears olive-green at the threshold, distinctly green at the 6th J.N.D., yellow-green at the 10th, greenish-yellow at the 18th, with still a tinge of green at the 26th, attaining a good yellow at the 36th, which faded into a whitish-yellow beyond the maximum. Green does not manifest such striking changes of hue with change of intensity. It appears blue-green at the threshold, attains a pure green around the 50th J.N.D., becoming progressively more yellow beyond the maximum. Blue comes in as a purple at the threshold, retains a tinge of this even to the 49th J.N.D., then becoming pure blue, and manifesting no hue changes as it passes into white beyond the maximum.

To summarize, then, the data presented for showing the selectiveness of the eye's chromatic response to wave-length and its change with change of intensity, it may be stated that at the threshold was found that the eye is most sensitive to color in the following order (*A*) with the dark surrounding field: green, yellow-green, blue, blue-green, yellow, red and orange. (*B*) With the light surrounding field the order became: blue-green, green, blue, yellow-green, red, yellow and orange. At the point of maximum saturation, with the dark surrounding field the eye was most sensitive to yellow-green, then to green, orange, blue, blue-green, red and finally yellow. With the light surrounding field at the maximum, the sensitivity decreases in the following order: yellow-green, green, orange, blue-green, blue, red and yellow.

NOTE: The Editors alone are responsible for the acceptance of this article, Professor Ferree having advised against its publication.